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Food and Habitat Selection of Male Burrowing Owls (*Athene cunicularia*) on Southern Alberta Grasslands

By

Robert Alan Sissons

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science

in

Wildlife Ecology and Management

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Dr. A. Lee Foote

Date: Sept. 29, 2003

Abstract

In 1998 and 1999, I investigated components of male Burrowing Owl foraging ecology on the native grasslands of southern Alberta. Home ranges for 11 owls in Alberta ranged from 0.34 to 7.56 km^2 and averaged 0.87 km^2 larger than previously reported for Saskatchewan (3.28 vs. 2.41 km^2). Male owls tended to select low-lying, emphemeral wetland areas and associated edges over grasslands and anthropogenic features. Structurally, foraging sites were found to have a significantly taller, dense vegetative cover than random sites. Dominant prey items by biomass include *Peromyscus maniculatus, Lagurus curtatus*, Silphid and Carabid beetles, and grasshoppers. *Peromyscus maniculatus* were found to respond negatively and beetles and grasshoppers responded positively to an index of current grazing pressure. Beetles responded positively to litter depth, while grasshoppers responded positively to litter cover. Foraging and nesting sites have distinctive habitat qualities that can be managed for by grazing practices that emphasize landscape heterogeneity.

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There are numerous people with whom I have had the pleasure of working with on this and other projects concerning Burrowing Owl conservation. Troy Wellicome was the person who first introduced me to this intriguing species and gave me my first experience working in a prairie ecosystem; I am forever indebted to him for the opportunity. I am deeply appreciative of Helen Trefry and Geoffrey Holroyd who provided much needed leadership and enthusiasm in the field and throughout my graduate program

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CHAPTER 1.

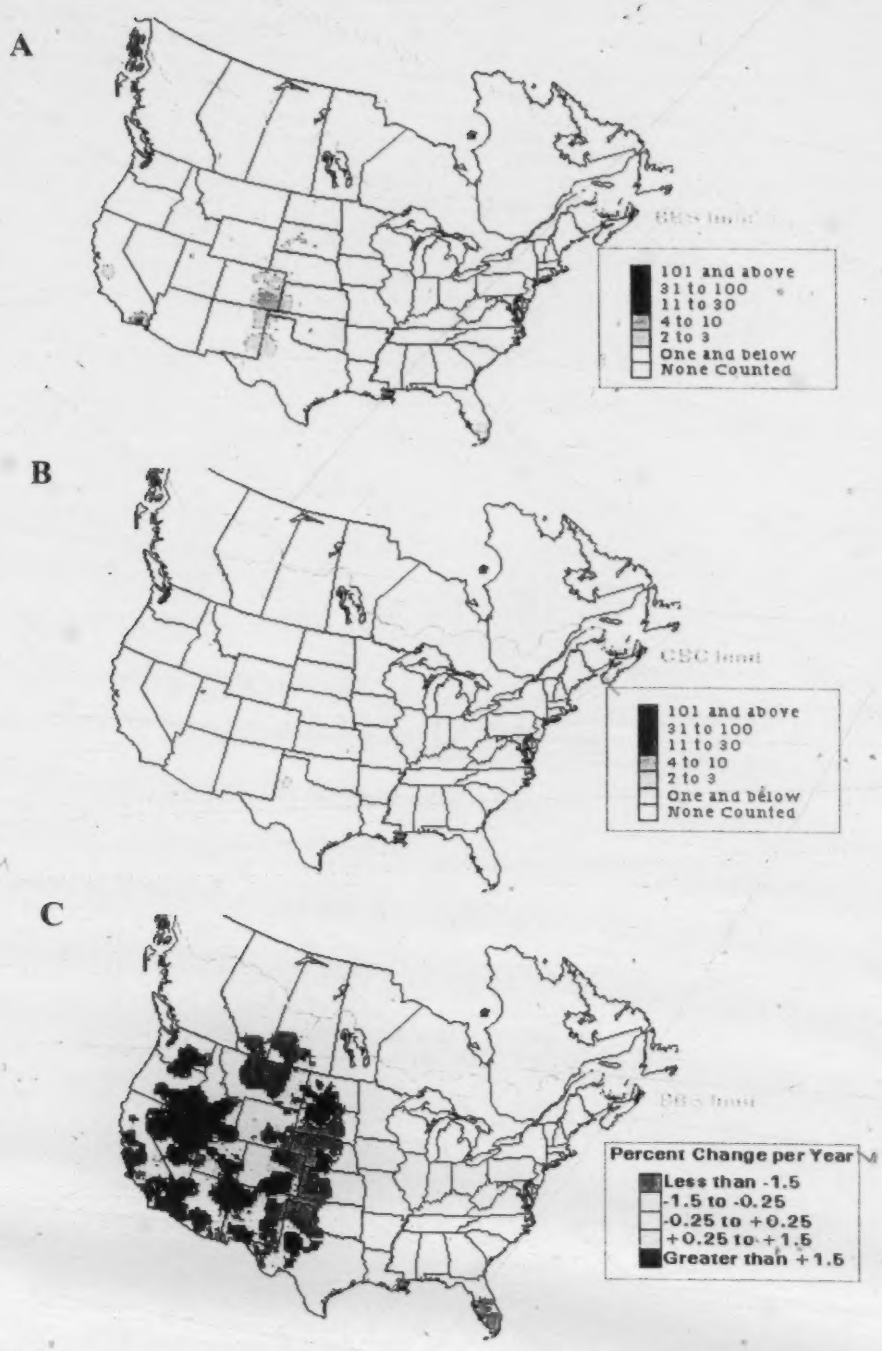
INTRODUCTION TO WESTERN BURROWING OWL (*ATHENE CUNICULARIA HYPUGAEA*) ECOLOGY AND THESIS OVERVIEW

1.0 INTRODUCTION TO BURROWING OWL ECOLOGY

1.0.1 Distribution and Taxonomy

The Burrowing Owl (*Athene cunicularia*) is a small bird of prey found on open grasslands, shrublands, and deserts of the Western Hemisphere. Historically distributed from southern Canada in the north to Tierra del Fuego, Argentina in the south, the species has undergone extensive range reductions, particularly in northern and southern regions and on islands of the Caribbean archipelago. The species consists of approximately 21 sub-species, most of which are endemic to the Caribbean island groups and South America. In North America, two sub-species are recognized with *A. c. hypugaea* occupying western North America and Mexico and *A. c. floridana* inhabiting south and central Florida and the Bahamas (Clark 1997; Fig. 1.1a).

The Western Burrowing Owl's (*A. c. hypugaea*) breeding range extends from the northern Great Plains and interior grasslands of the Pacific Northwest, south to California, northern Texas and northern Mexico. The Great Plains population of this sub-species is thought to winter primarily in shrub and agricultural lands of coastal Texas and central Mexico (Geoffrey Holroyd pers. comm.). Populations from the interior grasslands of the Pacific Northwest are thought to migrate to southern California while some individuals from California, Texas, and northern Mexico remain year round on their breeding grounds (Wellicome and Haug 1995).



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1.0.2 Population Status and Trends

Western Burrowing Owl populations have undergone a precipitous decline in numbers throughout most of their range (James and Espie 1997, Sheffield 1997; Skeel *et al.* 2001, Figure 1.1c) with the most severe declines occurring in the northern and eastern portions (Wellicome and Haug 1995, Hjertaas *et al* 1995, Wellicome 1997, Kirk and Hyslop 1998, Houston and Schmutz 1999). More specifically, the owl is virtually extirpated from Manitoba (DeSmet 1997) and is no longer found in British Columbia (Wedgwood 1978), Minnesota, Iowa, and the eastern portions of the Dakotas, Nebraska, Kansas, Oklahoma and Texas (see Figure 1 in Wellicome and Holroyd 2001). These declines have led to the national listing of the western Burrowing Owl as Endangered in Canada, Threatened in Mexico, and a species of concern in the United States (James and Espie 1997, Holroyd *et al.* 2001). Regionally, the species is listed as Endangered in Saskatchewan, British Columbia, and Manitoba and Threatened in Alberta with some level of formal protected designation in most states where it occurs (Sheffield 1997, Holroyd *et al.* 2001).

1.0.3 Breeding Ecology

Burrowing Owls typically arrive on their breeding grounds in Canada from mid- to late April, with the earliest known arrival occurring in late March (Wellicome 1997). Re-use of nest burrows is well documented, but more commonly, owls show fidelity to a specific nesting area (Dechant *et al.* 1999). Males tend to arrive approximately one week prior to the female (Wellicome 2000) and are the sole provider of food for the female and newly hatched young (Martin 1973, Haug *et al.* 1993). Burrowing Owls have the unique characteristic of nesting below ground in abandoned burrows of fossorial mammals

(mainly species of ground squirrels *Spermophilus*, badgers *Taxidea*, and prairie dogs *Cynomys* species; Haug *et al* 1993) that pairs line with dried cattle or horse manure (Wellicome and Haug 1995). The female lays one egg every 1.5 days, averaging nine eggs to a clutch, but have smaller clutches when nests are initiated later in the breeding season (Wellicome 2000). Juvenile owls are altricial, start emerging from the burrow chamber at 10-15 days of age, and can begin movement to satellite burrows at approximately 25 days (Haug *et al.* 1993). Owlets can sustain flight at approximately five weeks and are considered independent of the adults at six weeks when fledging occurs (Wellicome and Haug 1995). Migration occurs in late August to early October with the adults leaving an area prior to the juveniles (King 1996, Todd 2001).

1.0.4 Causes of Decline

There is not a single documented source that explains the precipitous decline of Burrowing Owl populations across its range in the northern Great Plains (Hjertaas *et al.* 1995). The most apparent cause of population decline is habitat loss and degradation on the breeding grounds (Haug *et al.* 1993, James and Espie 1997). Agricultural development on the Canadian prairies has resulted in the direct loss of breeding habitat; more then 80% of the Mixed Grass prairie has been cultivated in western Canada since settlement in the 1800's (Samson and Knopf 1994, Peltzer 2000). This habitat loss has led to a concomitant decrease in the availability of nesting sites and foraging habitat in addition to other, indirect, negative impacts, including increased predator density, pesticide use, and increased competition for limited resources (Hjertaas *et al.* 1995, Warnock 1996). On the remaining patches of suitable habitat, an interrelated factor implicated in Burrowing Owl decline is the continued persecution of fossorial mammals

due to their disturbance of croplands and competitive habits with the livestock industry (i.e. forage removal; Carrier and Czech 1997). It must be noted, however, that Burrowing Owls are highly dependent on the remaining rangelands that are managed for livestock, primarily beef production. Indeed, Burrowing Owl conservation is seemingly compatible with a sustainable commercial ranching industry (Schmutz 1994, Carrier and Czech 1997). Additional proximate factors in the decline of the Burrowing Owl include reduced productivity and increased depredation on the breeding grounds, as well as unknown mortality rates on migration routes and wintering grounds (Hjertaas *et al.* 1995).

1.1 Thesis Overview

Burrowing Owl habitat requirements on large tracts of native grasslands are generally unknown in Canada. Clayton (1998) studied the habitat requirements of juvenile owls in native prairie of central Alberta. Other studies have been situated in areas with significant agricultural fragmentation resulting in small, homogeneous patches of suitable breeding habitat within a mosaic of secondary habitat (Haug 1985, Wellicome 2000, Todd 2001). Studies on contiguous native prairie ecosystems have occurred in the United States, but have generally focused on reproductive ecology (Gleason and Johnson 1985, Bothello and Arrowood 1998), dietary analysis (Plumpton and Lutz 1993a), juvenile dispersal patterns (King 1996) or have provided nest site descriptions (Rich 1986, Plumpton and Lutz 1993b). Additionally, most of the Burrowing Owl populations studied on native prairie in the United States are distinct from Canadian populations in that they occur primarily on prairie dog (*Cynomys* sp.) towns as opposed to a reliance on Richardson's ground squirrels (*Spermophilus richardsonii*) and badger (*Taxidea taxus*) burrows in Canada (Haug *et al.* 1993).

I conducted a two-year study (1998-99) on the foraging ecology of Burrowing Owls on native grasslands of southern Alberta. The focus of this thesis is on resource selection of male Burrowing Owls during the breeding season at levels ranging from micro- and macro-habitat to prey species. Additionally, this research will supplement information on the breeding ecology of Burrowing Owls in Alberta. Specifically, Chapter 2 provides detailed information on the Eastern Irrigation District study area in southern Alberta as well as an overview of nesting success and productivity for the two-year study. Chapter 3 documents habitat utilization of the male owl, at scales varying from selection at the home range level to structural characteristics of the vegetation at individual foraging sites. Chapter 4 focuses on the dietary preferences of the owl and describes habitat characteristics of common prey species including small mammals and invertebrates. The final chapter provides an overview of management implications stemming from the conclusions of the previous chapters and describes further research needed to improve the conservation of Burrowing Owls in Canada.

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CHAPTER 2.

BURROWING OWL PRODUCTIVITY IN THE EASTERN IRRIGATION DISTRICT OF SOUTHERN ALBERTA.

2.0 INTRODUCTION

Determining the demographic parameters of an endangered species is an essential pre-requisite for the development of recovery goals (Hjertaas *et al.* 1995), setting priority actions to help recover a species to a defined level (Derrickson *et al.* 1998), and determining the success of these actions through long term monitoring (Noss 1990, Herkert and Knopf 1998). Demographic parameters are increasingly being used by resource management agencies for predictive models of the growth or decline of populations in response to management actions (Beissinger and Westphal 1998, Akcakaya 2000).

The estimation of productivity rates in Burrowing Owls is inherently difficult due to their underground nesting habit (Haug *et al.* 1993) leading to difficulties in accurately counting the number of young. Despite this challenge, fecundity, or more specifically, fledging rates, is one of the most well documented aspects of Burrowing Owl natural history across its range (see summary in Haug *et al.* 1993). Generally, reproduction is reported as the maximum number of young seen above ground or the number of young captured at the nest site (Gleason 1978, Green and Anthony 1989, James *et al.* 1997) but intrusive techniques involving the installation of artificial nest burrows have been used, improving the accuracy of clutch size and hatching rate estimates and our understanding of early chick development (Henny and Blus 1981, Wellicome 2000).

This chapter contributes to the existing literature on Burrowing Owl reproductive ecology by reporting on data from an unstudied population inhabiting native grasslands of southern Alberta.

2.1 Site Description

2.1.1 Climate

The study site is situated within the Dry Mixed Grass Ecoregion of southeastern Alberta (Strong and Leggat 1992). This area is characterized by hot, dry summers with an average summer (May to August) temperature of 15.8°C and precipitation of 178 mm making it one of the most arid regions of Alberta. Peak precipitation occurs in June with the hottest temperatures found in July and August (Table 2.1, Brooks Weather Station: Environment Canada unpubl. data). Winters are typified by shallow snow depths and frequent Chinook winds that tend to remove previous snow accumulation (Strong and Leggat 1992). Mean winter (November to February) temperature is –8.6 °C (Environment Canada 1998). For the period of this study, precipitation was above average, with June 1998 and June and July 1999 having almost twice the normal precipitation for the region (Table 2.1).

Table 2.1 Total monthly precipitation (PPT - mm) and mean daily temperature (TEMP - °C) for Brooks, Alberta in 1998 and 1999 compared to the 70-year (1918-1988) average values (data from Environment Canada, unpublished).

	March		April		May		June		July		August		Spring/ Summer
	PPT	TEMP	PPT	TEMP	PPT	TEMP	PPT	TEMP	PPT	TEMP	PPT	TEMP	Total PPT
1998	60.4	-3.2	17.9	8.0	24.1	13.8	101.4	15.3	29.8	21.1	8.8	20.5	242.4
1999	4.2	1.1	38.1	6.0	39.8	10.1	115.0	14.3	110.2	16.3	47.2	18.2	354.5
Average (70 year)	17.0	-2.7	27.2	5.1	39.1	11.4	65.5	15.9	38.1	18.4	36.4	17.5	223.3

2.1.2 Soils and Topography

Within the study area boundaries (Figure 2.1), Brown Chernozemic and Solodized Solonetzic great groups are the dominant soils. Solods and, to a lesser extent, Regosols

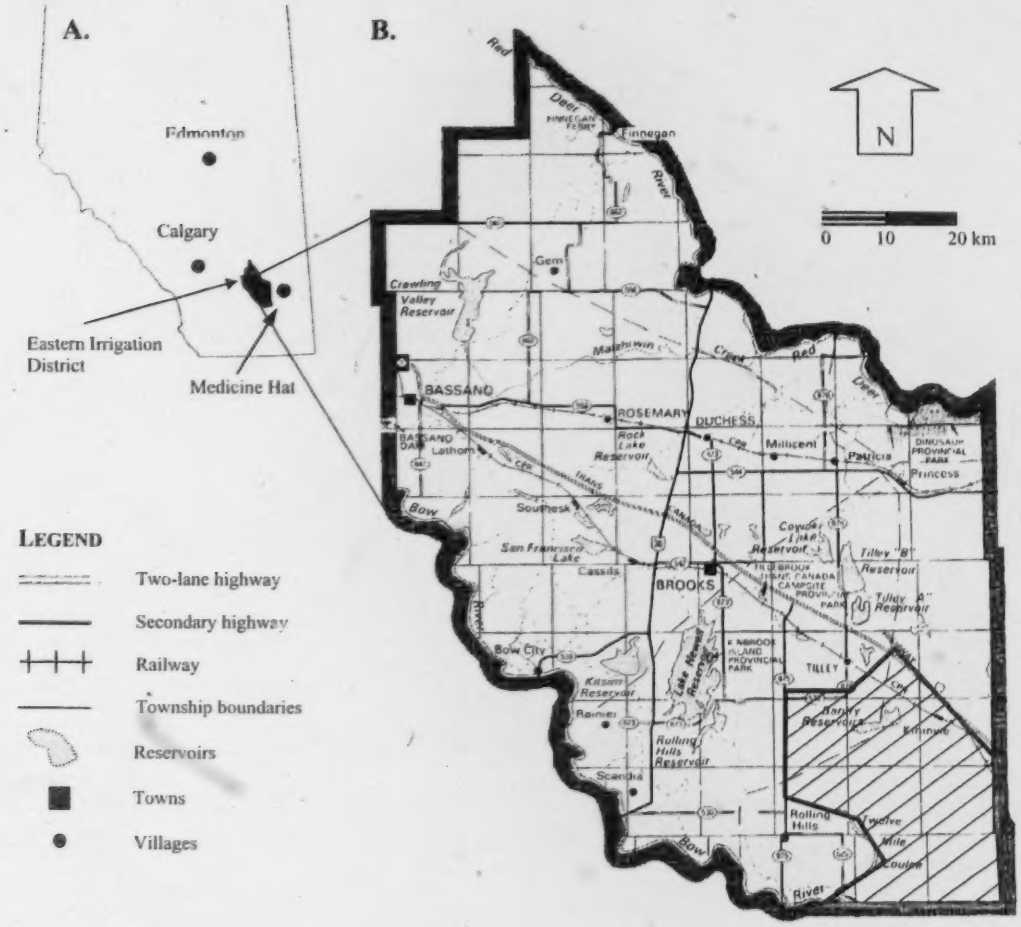

Figure 2.1 Location of the Eastern Irrigation District within Alberta (A) and the Burrowing Owl study area (gray hatching) within the Eastern Irrigation District (B). Burrowing Owl study area is bounded to the north by the Trans-Canada highway, to the west by irrigated croplands, and to the south and east by private grazing leases (images modified from EID and Gov. of Alberta 1995).

(stabilized sand dunes) make up the remaining soils. Slopes range from 2-5 % for most of the area with a smaller extent of 6-9 % slopes found in the extreme southeast (Kjearsgaard *et al.* 1983).

2.1.3 Vegetation

Vegetation is typical of the Mixed Grass Prairie. On upland sites, needle and thread grass (*Stipa comata* Trin. and Rupr.), blue grama grass (*Bouteloua gracilis* (HBK) Lag.), western and northern wheatgrass ((*Agropyron smithii* Rydb. and *A. dasystachyum* (Hook.) Scribn.) and thread leaved sedge (*Carex filifolia* Nutt.) are the dominant graminoids. Forbs are represented by a wide diversity of species including scarlet mallow (*Sphaerlacea coccinea* (Pursh) Rydb.), moss phlox (*Phlox hoodsii* Richards.) and pasture sage (*Artemisia frigida* Willd.). Depressions are characterized by foxtail barley (*Hordeum jubatum* L.), western wheatgrass and rushes (*Juncus* sp.), with gumweed (*Grindelia squarrosa* (Pursh) Dunal), prairie sage (*Artemisia ludoviciana* Nutt.), and docks (*Rumex* sp.) as common forbs. Sandy soils display an increased presence of wild rose (*Rosa woodsii* Lindl.) and are characterized by the occurrence of sandgrass (*Calamovilfa longifolia* (Hook) Scribn.) and sand dock (*Rumex venosus* Pursh). Common exotic species include Russian thistle (*Salsola kali* L.) and kochia (*Kochia scoparia* (L.) Schrad.), which invade and persist on disturbed soils. Tame pastures have been seeded to Russian wildrye (*Elymus* sp.) or crested wheat grass (*Agropyron cristatum* R. & S.), which is also commonly found on reclaimed oil and gas development sites and is noticeably encroaching into the surrounding native prairie.

2.1.4 Land Use and Ownership

The Burrowing Owl study site is located solely on private land held by the Eastern Irrigation District (EID). The EID is within Newell County, which is located in southeastern Alberta between the Red Deer River to the north and the Bow River to the south and centred by the town of Brooks (50° 33-N, 111° 51-W) (Figure 2.1).

The County of Newell is predominantly privately owned land used for irrigated and dryland forage, cereal crop production and beef ranching (EID and Gov. of Alberta 1995). The EID owns 43 % of Newell County and is the largest private landowner in Alberta. Of the more than 250 000 ha controlled by the EID, native prairie and seeded pastures account for 84 % of the total (78 and 6 %, respectively). The remaining EID owned land is utilized for irrigation including canals and reservoirs (~10 %), wetlands (3.5 %), and dryland or irrigated cultivation (0.5 %). Oil and, more commonly, shallow gas surface leases and associated developments presently encompass ~ 1.5 % of the area and are increasing annually (1991 data: EID and Gov. of Alberta 1995).

The study site, encompassing an area of approximately six townships (475 km^2), is found in the southeast corner of the EID (Figure 2.1). Portions of the study site (total area = 61 km^2) were previously selected as survey sites to monitor Burrowing Owl population trends in the province (Schmutz and Wood 1991, Shyry 1999; Figure 2.2) and were considered unavailable for this study. Nests that were located within trend blocks were monitored for productivity only by observation from a vehicle in order to minimize disruption of these nests that may confound the survey results. The region is predominantly native rangelands with some seeded pastures and dryland crops in the south. Reservoirs and wetlands with permanent open water are found in the northern and southwestern portions of the study site (Figure 2.2). Oil and shallow gas developments, related facilities and access roads are prolific and the major source of landscape fragmentation. Preliminary results from the trend surveys in the area indicate a stable population of Burrowing Owls, the only known seemingly stable population in Canada (Shyry 1999).

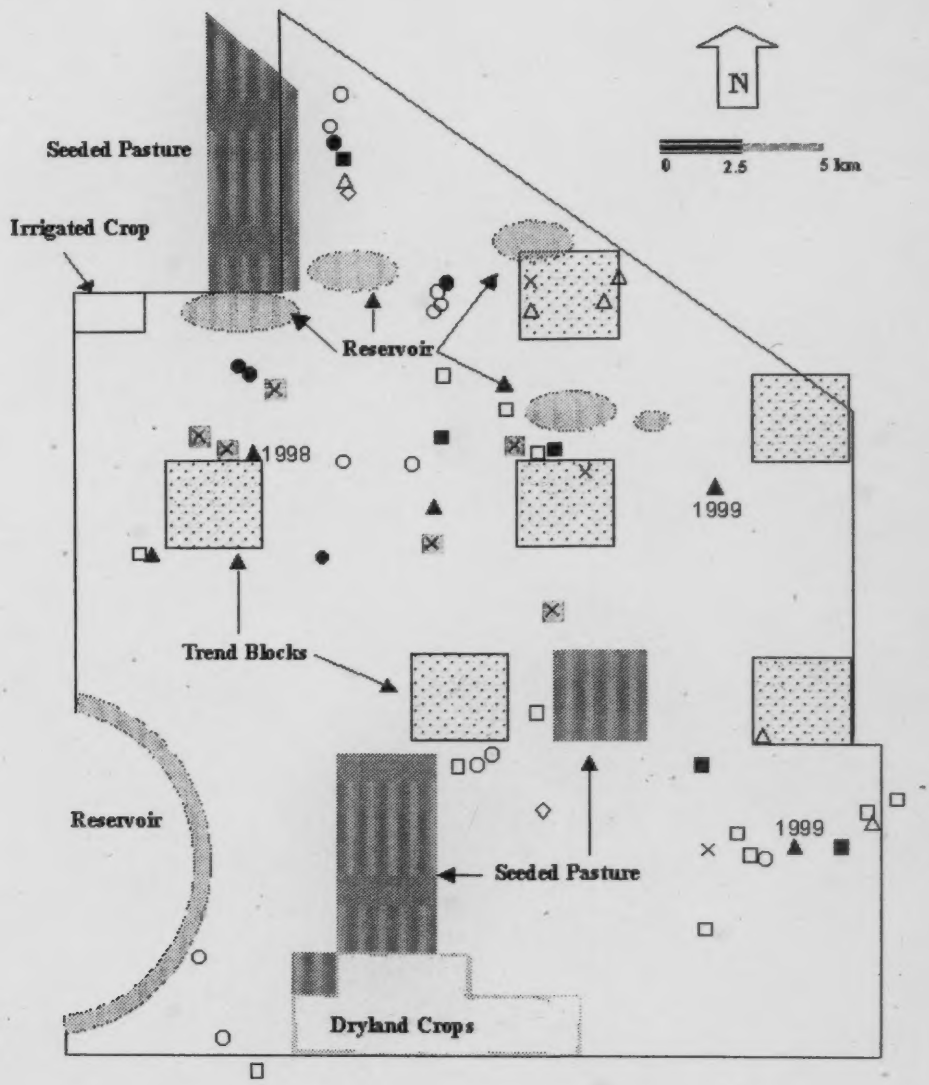

Figure 2.2 Burrowing Owl study area within the Eastern Irrigation District southeast of Brooks, Alberta. Nest site distribution within the study area is shown along with major habitat categories and prey sampling grids (X). Unclassified area is primarily native mixed-grass prairie interspersed with oil and gas developments and associated access roads and facilities. Trend blocks are areas not actively searched for nests (see text for further description). Nest site codes: O = 1998 nests; X = 1998 single owls; □ = 1999 nests; ◊ = 1999 single birds; and Δ = nest sites used in 1998 and 1999. Filled shapes indicate nest where the male owl had a transmitter attached. In cases where the nest was occupied in both years, the year the male had a transmitter attached is indicated. Scale is approximate.

2.2 METHODS

2.2.1 Nest Searching

Nests were located by vehicle along roads and trails at a moderate speed (15 - 25 km hr^{-1}). Using this methodology, an area of approximately 400 m on either side of the route was surveyed. This method inevitably resulted in some nests being missed as witnessed by nests being discovered later in the season on routes previously surveyed. The effectiveness of the survey method was not tested. Trend blocks, representing about 13% of the study area, were not extensively surveyed. Additionally, some portions of the remaining study site (~15%) had limited access and were therefore under surveyed.

2.2.2 Nest Monitoring and Productivity Assessment

Nests were visited on a three to five day schedule from when first discovered until young fledged or the nest failed. Frequent visits were necessary to determine successful pairing, stage of reproductive development, and collect pellets from the nest and associated roost sites for diet analysis (see Chapter 4). In 1998, nests were observed for 5-10 minutes prior to pellet collection until juveniles were first seen at the burrow entrance. Observations subsequently increased to approximately 20 minutes to improve counts of juvenile owl. Owlets were aged based on feather growth characteristics determined from published photographs of juvenile development (Priest 1997). The duration of the visit to the nest area was from 5 min to 15 min, depending on the proximity of roost burrows relative to the nest. All visitation details and activities at the nest were recorded, including timing and purpose of visit, number and sex of owls seen, and prey remains at the nest and roost burrow entrances. All pellets collected were separated by nest and roost, placed in paper bags, and stored for diet analysis.

Effort in obtaining productivity estimates was not consistent between years. In 1999 a concurrent study on juvenile survival and foraging habitat was initiated (Shyry, unpublished data), increasing the frequency and duration of late season nest observation and trapping of young. While the results presented here are from observation only, the increased effort in 1999 may complicate a statistical comparison of between year differences in reproduction.

2.3 Results

2.3.1 Nest Success

Active nest searching began on May 1, 1998 and April 22, 1999 and continued until approximately May 25 of each year, although nests continued to be located into early June. Only those nests found during the active nest-searching period were included in productivity and nest success estimates.

In 1998, 24 sites with owls were discovered during the active nest searching period with an additional five sites discovered later in the season (Figure 2.2). Two of these were on private land or in trend blocks and were not monitored. Of the remaining sites, one was determined to be a single bird – a male according to plumage and behaviour. The remaining 21 sites can all be considered nesting attempts; 13 of them successfully fledged young (62% success rate, Table 2.2).

Initially, 1999 was similar to 1998, with 24 sites found during the active nest searching period and an additional seven sites found later in the season. Two sites were single males with the remaining 22 active nesting attempts. Nest success was improved from the previous year, with 18 nests fledging young (82% success rate, Table 2.2). Eight

nest sites from 1998 were re-used in 1999 – six of which were successful in 1998 and all were successful in 1999.

Table 2.2 Summary of nest success and productivity for Burrowing Owls on the EID study site in southern Alberta for 1998 and 1999.

	1998	1999	Average
Nesting Attempts	21	22	21.5
Nests Failed	8	4	6
Nest Success Rate	62 %	82 %	72%
Productivity – per nest attempt	1.8 young	3.3 young	2.6 young
Productivity – per successful nest	3.1 young	4.1 young	3.6 young

2.3.2 Productivity

The number of young was determined by observation and productivity was assessed as the maximum number seen during the observation period. This may result in an over estimation of actual fledging rate since some juveniles may subsequently die. Alternatively, if all the young were not seen at the burrow entrance at the same time, the true number that reached fledging age may actually be greater. These limitations in mind, the estimated number of fledglings on the EID study site varied between years with 1998 (34 young) being much lower than 1999 (73 young, Table 2.2).

2.4 Discussion

The values for nest success rates in the EID study area are within the range reported for other Burrowing Owl populations in western Canada. James *et al.* (1997) report nest success rates ranging between 45% and 85% over seven years of data collection on a declining population near Regina, SK. Similarly, studies in central Alberta and southern Manitoba (reported in Hjertaas 1995) describe nest success values from 54% to 97% and 50% to 89%, respectively. However, Haug's (1985) reported success rates of 51 % and 64%, during two years of owl monitoring near Saskatoon, SK, are

lower than that found for this study. All of the above studies correspond to populations that have undergone extensive declines (Shyry 1999, Todd 2001), while trend block surveys located primarily within the boundaries of the EID study site suggest a stable population (Shyry 1999, Scobie and Russell 2000).

Fledging rates for the EID population also fall within the range of values reported for previous Canadian studies (1.1 – 5.5 young per nest attempt; 2.1 – 6.3 young per successful nest; Haug 1985, Hjertaas *et al.* 1995, James *et al.* 1997). The average reproductive values for the two-year EID study (2.6 young per nest attempt; 3.6 young per successful nest; Table 2.2) tended to be lower then those reported for the above studies individually (2.6 – 4.0 young per nest attempt; 4.3 – 4.8 young per successful nest) and combined (3.2 young per nest attempt; 4.5 young per successful nest). However, no conclusions can yet be drawn from the limited EID dataset.

Nest success and the number of fledglings produced on the EID study area changed dramatically between years for unknown reasons. Proximate factors may include extreme weather events or food shortages (Wellicome 2000) although neither was tested for this study. Mortality of adults, which contributed to nest failures, was higher in 1998 (3 males and 3 females) than 1999 (1 male and 1 female).

It is premature to predict trends for this population of Burrowing Owls due to the short-term data set. It is therefore essential to continue demographic monitoring for the EID Burrowing Owl population in order to provide the data needed to detect trends and to enable comparative work with the population in fragmented habitats of the Regina Plain (Wellicome 2000, Todd 2001). Trend Block surveys conducted annually by Alberta Environment document the abundance of nesting Burrowing Owls within defined areas,

but ineffectively measures demographic parameters due to insufficient effort (*i.e.* single nest visit to count young; Scobie and Russell 2000). The Trend Block monitoring program will provide managers with basic population trend information: is the population stable, increasing or decreasing? It does not, however, provide the information needed to determine which demographic component of the population is influencing this change. By incorporating measures of nest success and reproduction into the Trend Block program, managers will have a better understanding of how the structure of the population is changing over time in contrast to changes in density only, which can be a misleading indicator of population status (*i.e.* source-sink dynamics in a metapopulation model; Hanski and Gilpin 1997) or quality of the habitat (Van Horne 1983). However, determining the causal mechanisms of population change, that is answering the question of why the population is stable, increasing, or declining, is best answered through directed research (Morrison *et al.* 2001).

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CHAPTER 3.

HOME RANGE AND NOCTURNAL FORAGING HABITAT SELECTION OF MALE WESTERN BURROWING OWLS (*ATHENE CUNICULARIA HYPUGAEA*) ON NATIVE RANGELANDS OF SOUTHERN ALBERTA.

3.0 INTRODUCTION

Conservation and protection of endangered species and their habitats requires reliable understanding of their habitat requirements to effectively implement management strategies (Derrickson *et al.* 1998). Habitat requirements for the western Burrowing Owl (*Athene cunicularia hypugaea*) in Canada have been described for nest sites (Schmutz 1997), juvenile dispersal habitat (Clayton 1997), and nocturnal foraging sites of males in cultivated regions (Haug 1985; Sissons *et al.* 2001) but little is known of habitat requirements in large tracts of native rangeland. This study was designed to address this information gap by focusing on nocturnal habitat use by male owls during the brood rearing stage. The male owl is the sole provider of food during this stage of nest development, when nocturnal foraging is primarily for small mammals, which comprise the majority of prey biomass. Wellicome (2000) found that food supply during the brood rearing stage limited reproductive success more than the egg laying stage. Thus, habitats used by foraging males during the brood rearing stage may constitute critical habitats for Burrowing Owls.

3.1 STUDY AREA

The study site is found in the southeast corner of the Eastern Irrigation District (EID), which is within Newell County and centred on the town of Brooks (50° 33-N 111° 51-W) (Figure 2.1). This area is characterized by hot, dry summers with an average summer (May to August) temperature of 15.8°C and precipitation of 178 mm

(Environment Canada 1998) making it one of the warmest and most arid regions of Alberta. Mean winter (November to February) temperature is –8.6 ° C and are typified by shallow snow depths and frequent Chinook winds that tend to remove previous snow accumulation (Strong and Leggat 1992).

The study site encompasses an area of approximately six townships (475 km^2), portions of which were previously selected as survey sites to monitor Burrowing Owl population trends in the province (total area = 61 km^2; Figure 2.2) (Schmutz and Wood 1991, Shyry 1999) and were considered unavailable for this study.

The study site is predominantly native rangelands dominated by needle-and-thread grass (*Stipa comata*), blue grama grass (*Bouteloua gracilis*) and western wheatgrass (*Agropyron smithii*) with some seeded pastures of Russian wildrye (*Elymus* sp.) and crested wheatgrass (*A. cristatum)* and dryland crops. Reservoirs and wetlands with permanent open water are found in the northern and southwestern portions of the study site. Oil and shallow gas developments and related facilities and access roads are prolific and the major source of landscape fragmentation.

3.1 METHODS

3.1.1 Nest Searches and Monitoring

Burrowing Owls begin to return to the Canadian prairies from mid- to late April depending on spring weather conditions, with the earliest known arrival occurring in late March (Wellicome 1997). Active nest searches began on May 1, 1998 and April 22, 1999 and continued until approximately May 25 of each year although nests continued to be located into early June. Most nests were located by vehicle along roads and trails at a moderate speed (15 - 25 km hr^{-1}). Using this methodology, an area of approximately 400

m on either side of the route was surveyed. This method inevitably resulted in some nests being missed as witnessed by nests being discovered later in the season on routes previously surveyed. Trend blocks, representing about 13% of the study area, were not extensively surveyed. Additionally, some portions of the remaining study site (~15%) had limited access and were therefore under surveyed. All nests were monitored every 3 – 5 days throughout the summer to ensure the nest was still active, estimate productivity (Chapter 2), and collect regurgitated pellets for dietary analysis (Chapter 4).

3.1.2 Radio Telemetry

Given that the study's focus was on habitat use by breeding male owls, we commenced trapping once successful pairing had been observed and incubation was assumed to have been initiated. Noose carpets (Bloom 1987) were placed near the entrance to the nest and adjacent roost burrows and baited with dead laboratory mice to entice the male to walk on the carpet. The nest burrow was plugged to prevent the capture of the female owl, reducing the possibility of nest abandonment, which is thought to increase with handling of the female during earlier stages of nest development (Wellicome pers. comm.). Male owls would generally return to the nest burrow on their own, however, if after a 20 - 30 min period the male had not returned, we attempted to flush owls from roosts towards the carpeted burrows. Owls were generally caught within 1-2 hrs; trapping ceased if unsuccessful after three hrs. Some owls required several attempts to capture, while others declined to take part in the study. We took morphological measurements from all captured owls, including weight, wing cord, and the lengths of the central tail feather, and the fourth and ninth primaries. Each owl was

banded with a U.S. Fish and Wildlife Service aluminum band and a unique combination of colour bands.

Necklace style radio transmitters were attached in 1998 and a backpack style was used in 1999 (Holohil Inc. Newmarket, Ontario). The necklace transmitter collars were constructed of cloth-covered elastic bands, with the transmitter unit positioned in front and the antennae looped to point up from the neck of the owl. The elastic–antennae combination was wrapped in shrink tubing prior to attachment. The final installation was loosely fitted to permit ingestion of food and pellet regurgitation. Backpack transmitters were fitted snug to the owl's body with a 0.64 cm (0.25 in) Teflon ribbon harness. The transmitter unit was placed on the back of the owl between the wings, with the antennae perpendicular to the owl's body. Backpack transmitter attachment techniques were perfected on a captive raised adult male owl. Both transmitter packages weighed between 5 and 6 g, resulting in a maximum transmitter weight load of 4.0 % (male weight range: 149 – 176 g).

We used three element hand-held Yagi antennae and either a Lotek Inc. (SRX_400; Carp, Ontario) or Wildlife Materials Inc. (TRX 1000S; Carbondale, Illinois) receiver to relocate owls fitted with transmitters. Maximum range of the transmitters was 1.5 km on the ground with an 8 – 10 month battery life. In 1998, transmitters were left on the owls to aid additional research being conducted to determine Burrowing Owl wintering grounds, which were believed to be in southern Texas and northern Mexico (Holroyd and Trefry, Canadian Wildlife Service unpublished data). Attempts in 1999 to recapture owls to remove transmitters were unsuccessful.

Two researchers simultaneously recorded owl locations at 10-min intervals for a 30 - 60 min period using the direction of the strongest signal as the estimated bearing (Springer 1979). Researchers were in constant communication by walkie-talkie to ensure exact time synchronization of bearings. Locations of foraging owls were obtained from sunset (2100 H) to sunrise (0530 H) from early June until mid-July, corresponding to the hatching-to-fledgling stage of juvenile development. One evening session encompassed three to four owls, thus each owl was tracked every three to four days, depending on weather conditions. Researchers searched for scheduled owls until found, then commenced the 30 – 60 min telemetry session, ensuring complete coverage of each owl's foraging area. Telemetry was not conducted during periods of excessive rain or lightening storms, thus locations are representative of owl foraging under "optimal" conditions.

Location data were analysed using Locate II (Nams 1990), which calculates the estimated point location of the animal and gives the area of the associated error polygon. The error polygon is delineated by the intersection of the error arcs from two bearings, which are defined as the measured bearing $\forall$ the standard deviation. This approximates a 95% confidence interval for each bearing and the resultant error polygon has a 90% (that is 0.95^2) probability of containing the true animal location (Nams 1989). The error polygon method is only suitable for two bearing systems (Nams and Boutin 1991). The accuracy of the telemetry system for this study was assessed in the field and estimated to have a standard deviation of 4.5° of the true azimuth. With a two bearing system, the most accurate locations are achieved when the bearings intersect at a 90° angle, creating an almost square polygon. With increasing deviations from 90°, the error polygon

becomes increasingly ellipsoid. I therefore discarded simultaneous bearings that were ≤40° and ≥140° apart due to the extremely elliptical error polygons they created (9% of the readings).

The resultant point files were imported into ArcView 3.2a with the Spatial Analyst extension (Environmental Systems Research Institute, Redlands, California). Home ranges were constructed using the Home Range Extension program developed by Rodgers and Carr (1998). Two methods were used to estimate the home ranges of each owl: the minimum convex polygon (MCP) method (White and Garrott 1990) and the adaptive kernel method (Worton 1987). The MCP method constructs a polygon around all peripheral points of the data set, with the standard 95% level used to eliminate infrequent large distance movements (White and Garrott 1990). The kernel method considers probability contour intervals of the utilization distribution (e.g. 95% probability of use), with the adaptive kernel estimate including nearest neighbour information; that is, areas with greater concentrations of points receive a greater weight within the utilization distribution (Worton 1987). The main difference between these two methods is that the MCP only gives the boundary of the animal's area of use while the kernel method provides a measure of the intensity of use within the animal's range (Worton 1987). This study used the 95% kernel, again to reduce the influence of outliers, to describe the home range of the owls and the 50% kernel to estimate core areas used by the owls. The MCP method is included for comparison with previous work on Burrowing Owl home ranges in Saskatchewan (Haug 1985, Sissons *et al.* 2001).

3.1.3 Habitat Quantification

3.1.3.1 *Microhabitat Variables*

Habitat variables were recorded at 8 – 12 randomly selected foraging locations for each of four owls in 1998 and five owls in 1999. At least one foraging location per telemetry session was chosen to ensure adequate representation of potential temporal differences in the owl's choice of foraging habitat. Paired random sites were also sampled for each foraging location in 1999. Random locations were selected by moving 200 m in a random direction from the foraging site. Sampling took place along transects defined by the maximum width and length of the error polygon for that location. Random sites used the same sampling configuration as its paired foraging location.

Percent cover using Daubenmire cover classes within a 20 X 50 cm quadrat (Kent and Coker 1992) was recorded for each plant species, bare soil, litter, and moss/lichen. The total number of quadrats sampled for each site ranged from 15 – 25, depending on the size of the area being sampled. Silver sage (*Artemisia cana* Pursh) height was measured for each individual plant located within a 1 m buffer of each transect. The Robel pole vegetation obstruction index, defined as the highest point where the vegetation completely obscures the pole from a distance of 4 m (Bureau of Land Management 1996), was also recorded every 5 m along each transect.

Between year differences in foraging sites were compared using the Kolmogorov-Smirnov two-sample test prior to pooling data. Foraging and random sites were compared using the Mann-Whitney nonparametric test (Wilkinson 1997). Statistical significance was set at $p \leq 0.05$; all procedures were performed using SYSTAT 7.0 software (SPSS Inc. 1997).

3.1.3.2 *Macrohabitat Variables*

Habitat classification was performed in ArcView 3.2a GIS using 1:20 000 digital colour aerial photos (1995 and 2000), with ArcView shapefiles delineating anthropogenic features, including pipelines, oil and gas lease locations, access roads, high speed gravel roads, and fence lines (1999 data; courtesy of the Eastern Irrigation District, GIS division). Habitats were classified as upland native pasture, tame pasture, cropland, depressional (low-lying ephemeral) areas, and vegetated sand dunes. In addition, a 10 m buffer around all depressional and vegetated sand dune areas was defined as edge habitat. Open water contained in large reservoirs was considered non-habitat. Anthropogenic features were combined into four classes: 1) fenced features, including fenced lease sites and pasture fence lines, 2) dugouts, 3) high speed gravel roads, and 4) all other features including unfenced lease sites, trails, railroad tracks, and pipelines.

3.1.4 Habitat Selection

The delineation of used and available habitat categories was performed at the individual level (Design III; Manly *et al.* 1993). Availability was defined by the area contained within a buffer with a radius equal to the maximum distance travelled from the nest by each individual owl. All habitats within this radius were considered available to that individual because the owl demonstrated the ability or willingness to travel this maximum distance. This approach assumes there are no other factors, such as intraspecific competition, restricting habitat utilization. Additionally, it assumes that upon arrival in the spring, Burrowing Owl's first select a nest burrow, and then find suitable foraging habitat within the surrounding area; an assumption that is untested.

Habitat selection was analysed at three levels, closely following the second and third order selection indices of Johnson (1980). First, selection was considered by comparing the composition of habitats within the 95% kernel home range versus those available, as defined above. Second, a comparison of habitat composition within the 50% kernel core area versus available habitat was performed. Finally, the third level compared a sub-sample of foraging sites with the home range habitat composition. Foraging sites were sub-sampled to maintain a minimum 20 min separation between successive locations with the 20 min duration considered sufficient time to allow the owl movement between different habitats within the home range (Swihart and Slade 1998; Otis and White 1999). Foraging sites were not considered points due to the error associated with telemetry readings (see Nams 1989), but were buffered by an area equal to the mean error polygon size calculated for each owl. Habitat composition was determined for each buffered point separately then summed over all points to attain the foraging habitat composition for each owl. Specifically, given $\boldsymbol{H}$ habitat types with $x_1, x_2, \ldots, x_H$ representing the proportion of habitat i within foraging buffer x, the $\sum_{i=1}^{H} x_i = 1$ for foraging buffer x. The total proportion of habitat i for all foraging buffers is given by $\frac{\sum_{j=1}^{n} x_{ij}}{n} = \mathrm{X}_i$ where n equals the total number of foraging buffers for that owl and $i = 1, 2, \ldots \boldsymbol{H}$ for habitat types 1 to $\boldsymbol{H}$.

This method incorporates telemetry error into the estimate of foraging habitat use and recognizes that Burrowing Owls (indeed most birds of prey) scan a larger area for prey from a perch or while hover hunting than that defined by a single dimensionless

point. Habitat composition within this search 'disk' (Loehle 1990; see also Gautestad and Mysterud 1994, Loehle 1994) may contain more then one habitat type and this complexity should be included in foraging habitat analysis. The amount of area encompassed by the search area is dependant on the foraging height and the perception angle of the animal and can be influenced by vegetation density as well as prey size and activity (Janes 1985), factors that were not accounted for in this study.

3.1.4.1 *Statistical Approach*

Compositional analysis is an analytical method originally proposed by Aitchison (1982) to address the unit-sums constraint inherent in data sets containing proportional values. The method has been applied in wildlife habitat utilization (Aebischer *et al.* 1993a, Pendleton *et al.* 1998), behavioural (Elston *et al.* 1996), and survival (Aebischer *et al.* 1993b) studies. The unit sum constraint is where the sum of all habitat proportions within a use or available area is one, or equivalently, $\sum_{i=1}^{H} x_i = 1$ where x_i is the proportion of habitat i in the animal's use or available area and $\boldsymbol{H}$ is the total number of habitat types. Subsequently, the measures of use of (or availability of) habitats x_i (where $i = 1, \ldots \boldsymbol{H}$) are linearly dependent; that is, an increase in use of one habitat must lead to decreased use of the remaining habitat types and *vice versa* (Aebischer *et al.* 1993a). In order to remove the linear dependency, Aitchison (1982) advocated the log-ratio transformation of the data sets where $y_i = \ln(x_i / x_j)$, ($i = 1, \ldots \boldsymbol{H}$, $i \neq j$), x_i is the proportional use of habitat i and x_j is proportional use of habitat j. The choice of which habitat to represent j is inconsequential (Aebischer *et al.* 1993a), as long as j is the same for all transformations within the set of analyses to be performed (Aitchison 1982). This transformation is applied to both the use and available matrices resulting in separate matrices of log-ratio

transformed data with $H - 1$ columns and one row for each animal (Aebischer *et al* 1993b).

In order to assess habitat selection, a matrix D (equivalent to the ratio of use versus expected), is created where $D = U - A$ and U is the matrix of habitat use data and A is the matrix of habitat available data (Pendleton *et al.* 1998). To test the null hypothesis of resources used in proportion to availability, a likelihood ratio test statistic of the form $\neq = \frac{|R_1|}{|R_2|}$ is created where R_1 is the mean corrected sums-of-square and cross products matrix of D and R_2 is the raw sums-of-square and cross products matrix of D (Aebischer *et al.* 1993a). They found that $-N\ln(\neq)$ follows an approximate X^2 distribution with $H - 1$ degrees-of-freedom with N equal to the number of animals.

Assuming non-random use of habitats (*i.e.* a significant $\neq$ value), it is possible to assess where use deviates from random. To determine this, a comparison of the log ratios for used habitats with the matching log ratios for available habitats is required where the habitat used in the denominator of the log ratio changes for each pairwise comparison. This gives a matrix of values of the form $\ln(\frac{x_{Ui}}{x_{Uj}}) - \ln(\frac{x_{Ai}}{x_{Aj}})$ for each element where ij = 1, 2, ...H, $i \neq j$; and U and A represent used and available habitat proportions, respectively. The rows of the resultant matrix are the habitats used as numerators in the equation and columns are the habitats used as denominators. By averaging all animals in the study, mean and standard error values can be calculated for each element in the resultant matrix. The sign of the mean value can be interpreted as indicating preference (+) or avoidance (–) of the row habitat versus the column habitat with the significance of this relationship determined by the mean/standard error ratio, which is comparable to the

t distribution. Additionally, the sum of positive values for each row in the average resultant matrix can be used to rank habitats in order of increasing relative use with 0 being the least preferred and $H - 1$ being the most preferred habitat type (Aebischer *et al.* 1993a,b).

Problems associated with this procedure arise when zero values occur within the use or available matrices, as a zero value in the log ratio transformation is invalid. A substitute value of 0.001 was used to correct for the presence of zero values in the use matrix, which is analogous to stating that use of this missing habitat is so small as to not be measurable (Aebischer *et al.* 1993a). Zero values in the available matrix are more difficult to overcome, and cannot be "fixed" by simple replacement of a small substitute value. The best correction for this study was to drop three habitat categories from the analyses: stable sand dunes, crops, and tame pastures, since these habitat types were present for only one, one, and two owls, respectively. Additionally, available habitats were absent from the compositions for three owls at the third level of selection, requiring these individuals to be dropped from these comparisons (Aebischer *et al* 1993a) (Appendix 1.0). Analyses were performed using the Resource Selection for Windows program (Leban 1999) with a significance level of $p \leq 0.05$ for all tests.

3.2 Results 3.2.1 Telemetry and Home Ranges

Transmitters were attached to 17 male Burrowing Owls over the two-year study period, eight in 1998 and nine in 1999. One owl dropped its transmitter several days after it was installed while five other nest sites subsequently failed: one due to flooding, one due to the death of the female owl, and one due to mammalian depredation of the nest site, with the remaining two due to unknown causes. We attempted to continue following

the single males but, in three of five cases, they disappeared within days of nest failure. Of the remaining two males, one moved approximately 2-3 km north of the nest site and was subsequently found depredated by an avian predator 10-14 days following nest failure. The other male stayed at the nest site for the duration of the breeding season. The cause of this nest failure was never determined; the female owl was last seen at approximately the time when incubation should have started and was assumed to be brooding during the tracking period. Once it was realized the female had not been seen well beyond the time other female owls were again visible, the nest was deemed a failure and the male's data set dropped from future analysis. Tracking of two additional owls was shortened due, separately, to the death of the male and badger (*Taxidea taxus*) excavation of the nest burrow. Juvenile owls successfully fledged from the nest where the male died and two young approximately 14 – 18 days old were seen at the badger-depredated burrow prior to the event occurring. Telemetry data for these two males up to the time the incidents occurred were included in the dataset.

Telemetry commenced between June 10 – 16 in each year, except for two owls where tracking began on June 22, and was completed on July 15 in 1998 and July 23 in 1999. Telemetry on the male owl that died commenced on June 14 and ended on June 25, while the depredated nest was followed from June 14 to July 10.

A total of 880 usable telemetry locations from 149 sessions were collected for the 11 remaining owls, with an average of 5.9 ∀ 0.24 SE locations per session (Figure 3.1). Owls were located up to 4.0 km away from their nest site with a mean distance traveled

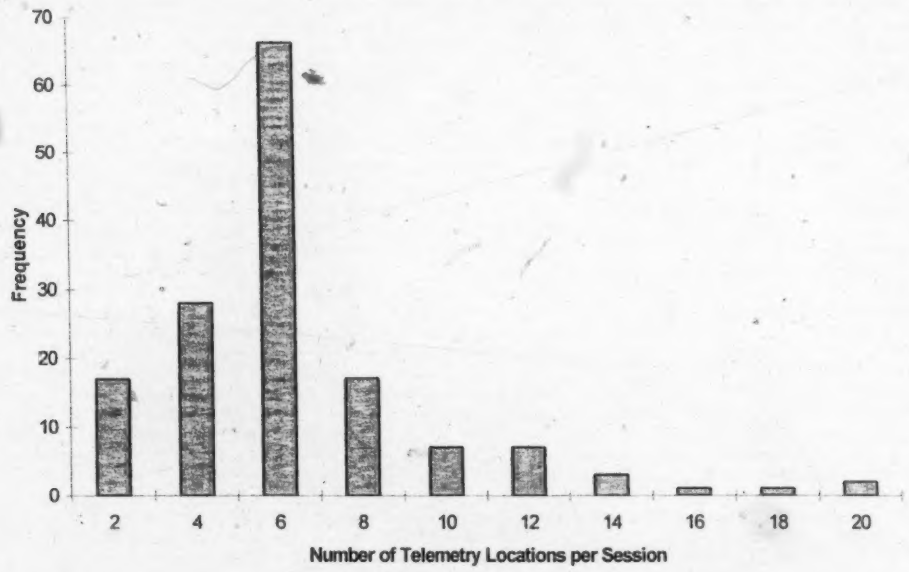

Figure 3.1 Number of telemetry based locations per session for eleven male Burrowing Owls. The mean number of locations per session is 5.9 ∀ 0.24 SE with a total of 880 locations for 149 sessions over the two-year study period.

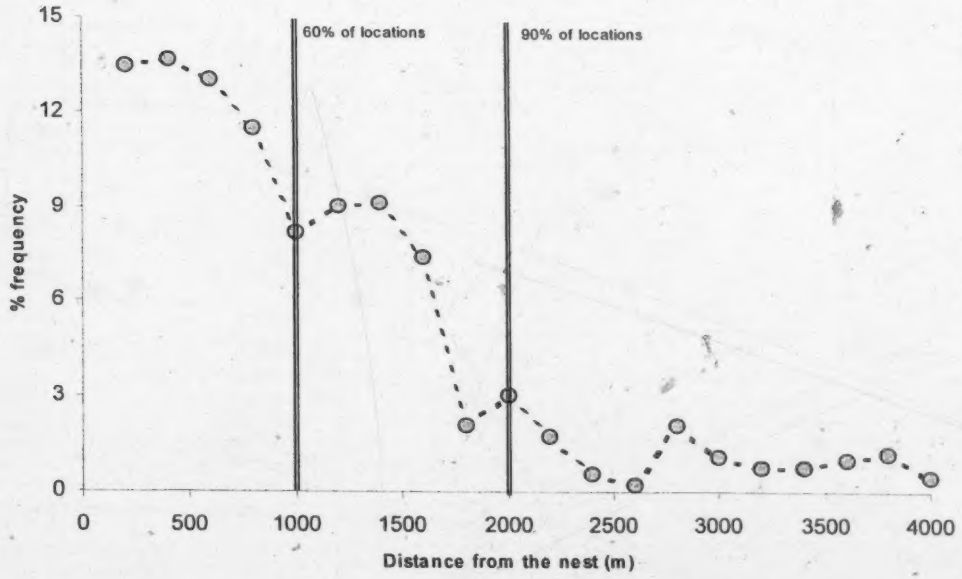

Figure 3.2 Percent frequency of distance from the nest for Burrowing Owl foraging locations for eleven male owls as determined from radio telemetry. The data set excludes all locations less than 50 m from the nest site (Haug and Oliphant 1990).

of 981 m ∀ 26.9 SE for all 11 owls combined, excluding locations found within 50 m of the nest site since these may not represent true foraging events (Haug and Oliphant 1990; Figure 3.2).

Home ranges (95% kernel) for four owls in 1998 ranged from 0.48 to 6.47 km^2 and from 0.97 to 4.83 km^2 for seven owls in 1999, while core areas (50% kernel) ranged from 0.05 to 1.23 km^2 and from 0.12 to 0.62 in 1998 and 1999, respectively (Table 3.1). Home ranges were found to stabilize after seven sessions or approximately 40 locations. All but one owl were followed for more than seven sessions, with the exception being the male that died prematurely after six sessions (Figure 3.3).

Table 3.1 Home range (95% Kernel) and core area (50% Kernel) sizes (km^2) for male Burrowing Owls in the Eastern Irrigation study site in 1998 and 1999. The minimum convex polygon (95% MCP) value is presented for comparative purposes to previous studies in cultivated regions of Saskatchewan.

	1998			1999		
	95% MCP	95% Kernel	50% Kernel	95% MCP	95% Kernel	50% Kernel
	1.04[AB]	1.12	0.16	3.69[A]	2.31	0.24
	0.39[D]	1.15	0.20	6.54	4.83	0.61
	7.56	6.47	1.23	3.13	3.86	0.62
	2.42	2.51	0.26	5.49	2.44	0.29
	0.34	0.48	0.05	2.06	0.97	0.12
				2.42[C]	2.20	0.25
				2.05	2.12	0.26
Mean	2.68	2.65	0.44	3.63	2.68	0.34
Mean (both years)	3.28	2.67	0.38			
Saskatoon, Haug (1982-3, n = 6)	2.41	n/a	n/a			
Regina, Sissons *et al* (1997, n = 4)	0.35	0.50	n/a			

A = same nest burrow different owls
B = Single male, values not included in averages
C = Nest depredated by badger after two young seen at burrow entrance, values from telemetry locations up to time of failure
D = Telemetry cut short due to death of male although young were successfully fledged

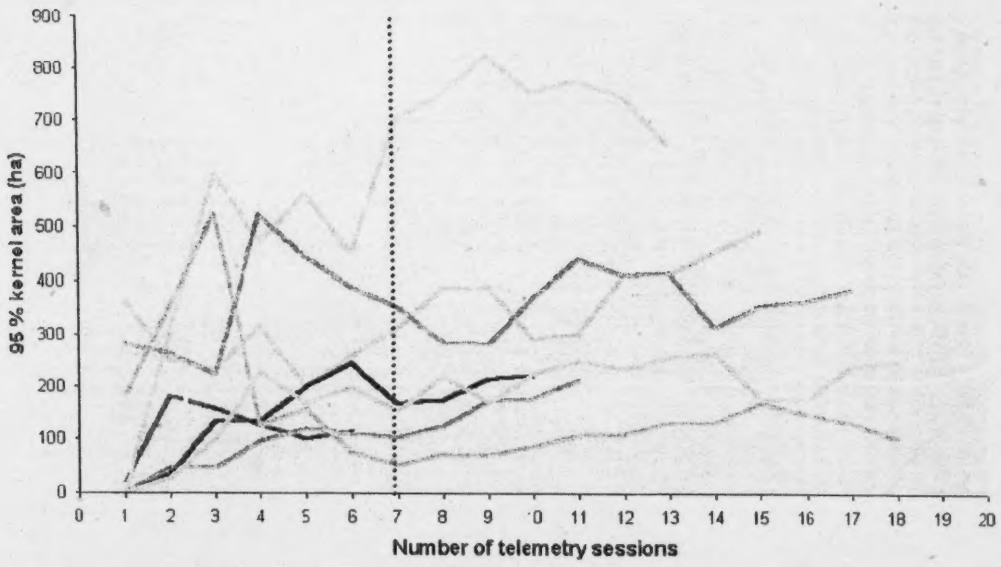

Figure 3.3 95% kernel area associated with number of telemetry sessions for 11 Burrowing Owls in the EID study area in southern Alberta. Each telemetry session represents a batch of location estimates as determined from radio telemetry (see Figure 3.1). Most home ranges stabilize after seven sessions, representing approximately 40 animal locations. See text for complete details of telemetry methods.

3.2.2 Habitat Selection

3.2.2.1 *Microhabitat Selection*

Five microhabitat variables were measured in 1998 on 48 foraging sites from four males and in 1999 on 50 foraging and paired random sites from five males. All habitat variables at foraging sites did not differ significantly between years (Kolmogorov-Smirnov two sample test; $p \geq 0.11$ for all comparisons), and were therefore pooled for comparison with random sites. Mean litter, soil, and moss cover and sagebrush height were not significantly different on foraging sites versus random sites ($p \geq 0.26$). However, foraging sites had a significantly greater mean Robel index score versus random sites, indicating selective use of areas with taller, dense vegetative cover (Table 3.2).

Table 3.2 Values of microhabitat variables measured at Burrowing Owl foraging and paired random sites in the Eastern Irrigation District study site in southern Alberta. Values were first averaged from 8-12 foraging sites per owl from four nests in 1998 and five nest sites in 1999 and five random sites in 1999. Yearly differences were tested prior to pooling foraging values (Kolmogorov-Smirnov two-sample test, $p > 0.11$ for all pair wise comparisons).

Habitat Variable	Foraging ($\bar{x} \pm$ SE)	Random ($\bar{x} \pm$ SE)	
% Litter cover	27.0 ± 2.3	22.9 ± 2.7	$U = 31.0$, df = 1, $p = 0.26$
% Soil cover	10.8 ± 2.2	12.7 ± 2.0	$U = 17.0$, df = 1, $p = 0.46$
% Moss cover	30.6 ± 2.6	34.2 ± 2.3	$U = 18.0$, df = 1, $p = 0.55$
Robel value	6.4 ± 0.5	4.5 ± 0.5	$U = 39.0$, df = 1, $p = 0.03$
Artemisia height 3rd quartile (cm)	22.1 ± 5.8	18.5 ± 7.6	$U = 25.0$, df = 1, $p = 0.73$

3.2.2.2 *Macrohabitat selection*

Three levels of comparison were examined to determine Burrowing Owl habitat selection at different scales of observation: the home range versus available habitat, the core area versus available habitat, and finally, foraging sites versus the home range composition. Notably, at all levels of comparison, the three dominant habitat types by area (native uplands, depressions, and edges) maintained a consistent ranking: depressions, then edges, then native uplands, with all other habitat types changing their rank independently of each other as the level of comparison changed.

Habitat compositions of Burrowing Owl home ranges were found to differ significantly from the composition of available habitats ($X^2 = 18.8$, $df = 6$, $p < 0.01$). Habitat ranking at the home range level gave the following order from preferred habitats on the right too avoided on the left:

Dugout > Depression > Edge > Roads > Native Uplands > Other > Fenced

Preferred ⟶ Neutral ⟶ Avoided ⟶

with underlined habitat types not differing significantly from each other (Appendix 2.0).

At the core area level, used habitat composition was also found to differ significantly from available habitat composition ($X^2 = 16.2$, $df = 6$, $p = 0.01$) giving the following habitat rankings from preferred too avoided:

Depression > Edge > Native Uplands > Other > Fenced > Dugout > Roads

Preferred ⟶ Neutral ⟶ Avoided ⟶

again with underlined features not differing significantly (Appendix 2.1).

Habitat selection within the foraging buffer versus home range level was found to be overall significantly different ($X^2 = 15.9$, $df = 6$, $p = 0.02$) with the following ranking:

Fenced > Depression > Edge > Native Uplands > Roads > Other > Dugout

but with no preference scale possible because no one habitat type was significantly preferred or avoided (Appendix 2.2).

Proportions for habitats excluded from analysis; tame pasture, crops, and stable sand dunes, are given in Appendix 1.0. Tame pasture was available for only two owls and was consistently used in lower proportions by one owl and in greater proportions by the second owl at each level of comparison. Irrigated crop was available for one owl and was used in greater proportion at the home range versus available level (20.9% versus 10.1%), but was used in lower proportions at the core area and foraging levels (2.6% versus 10.1% and 16.6% versus 20.9%, respectively). Stabilized sand dunes were available for one owl and were used in greater proportions at the home range and core area level versus available (45.6% and 36.9% versus 28.1% respectively), but used in equal proportions at the foraging level (46.2% versus 45.6%).

3.3 Discussion

This study was initiated with the goal of determining what types and structural characteristics of habitats typical of a native grassland ecosystem are preferred by male Burrowing Owls during nocturnal foraging bouts during the breeding season.

Only two detailed studies of Burrowing Owl home range characteristics have previously been conducted, both in heavily cultivated regions of central and southern Saskatchewan. Minimum convex polygon home ranges for six males were described by Haug (1985) in a study conducted near Saskatoon, SK and were found to be on average,

31% smaller than in this study (2.41 km^2 versus 3.28 km^2 respectively; Table 3.1). Results from an additional study near Regina, SK (Sissons *et al.* 2001) found substantially smaller average home ranges for four males (0.35 km^2), but the year in which the study was conducted was admittedly not representative of normal conditions due to an irruption in the meadow vole (*Microtus pennsylvanicus*) population (Poulin *et al.* 2001).

These studies suggest that male Burrowing Owls foraging in fragmented; often cultivated habitats of Saskatchewan are able to acquire adequate prey within a smaller foraging area and adjust their home range requirements during times of abundant prey. Severe agricultural modification of the landscape may have led to an artificially increased population of small mammals. However, data from Saskatchewan does not seem to support this hypothesis. In 1992 and 1993, Wellicome (unpublished data) documented slightly greater densities of small mammals for the Regina Plain (0 = 12.2 mice/100 trap nights) than found on the EID study site (0 = 11.0 mice/100 trap nights; 1999 data, see Chapter 4) and shows mice on pastures (native and tame) to occur at a lower density (0 = 6.8 mice/100 trap nights). Haug (1985) also reported much lower estimates of mice near Saskatoon (0 = 3.4 mice/100 trap nights). However, averaging mouse densities across the landscape may mask the occurrence of dense pockets of small mammals, which may be found closer to owl nest sites in the Saskatchewan study areas versus the EID study area. Other factors, unaccounted for by prey density estimates, may also be influencing this difference in the territory size of Burrowing Owls such as the availability of prey and intraspecific competition.

Other studies reporting on habitat utilization include King (1996), who followed three adult male owls from mid-June to mid-August in Idaho and reported MCP home ranges of 0.14 and 0.65 km^2 for two of the males that successfully fledged young. These could be, however, severe underestimates because no attempt was made to follow owls when the transmitter signal moved out of the range of permanent telemetry stations, which was indicated to be a frequent event (King 1996). Other researchers reporting on Burrowing Owl territories or habitat use either restricted observations to diurnal activities (Martin 1973), made suppositions from casual observations of owls seen away from the nest site (Butts 1971), or inferred habitat preferences from diet analysis and prey habitat associations (Gleason and Johnson 1985, Rich 1986, Green and Anthony 1989).

Male Burrowing Owls utilized habitat disproportionately to availability at all levels of comparison: home range, core areas, and foraging buffers. Patterns emerged as the analysis changed resolution from the home range to foraging level. For instance, dugouts were a highly ranked feature at the home range level but decreased to an unfavourable habitat at the foraging level. Fenced features had an opposite pattern – increasing in relative importance from the home range to foraging levels. Depressional habitats, and associated edges, were consistently higher ranked habitats, while native pasture and the remaining anthropogenic features were generally middle and lower ranked habitats respectively.

The high ranking of depressional areas and associated edge habitats was consistent with the significant selection at the microhabitat level for areas with higher, dense vegetative cover (Robel value) as this feature, in part, characterizes these habitat types. Dugouts are constructed within depressional areas and the change in rank from

first at the home range level to last at the foraging level indicates Burrowing Owl avoidance of depressions with dugouts or, in larger depressions, the portions influenced by the dugout. This may be related to changes in vegetative structure directly from cattle trampling or indirectly from modification of local hydrology (Kindschy 1996, Laubhan and Fredrickson 1997), which in turn can have negative effects on potential prey species (e.g. *Microtus* spp., Birney *et al* 1976).

The increased preference for fences at the foraging level may indicate a continued selection for edge habitats by owls. Fences can represent a separation between habitat types with different vegetation structure, either through different grazing regimes (*i.e.* differences in stock density and timing of grazing) or where the interior of fenced lease sites has been seeded to an exotic species.

The selection for areas of denser vegetation suggests that prey accessibility is not a limiting factor for the owls on this study site, contrary to that found for other raptor species (Bechard 1982, Preston 1990). It therefore follows that owls should be selecting habitats with the greatest density of prey items, in this case small mammals (assuming small mammals are the primary nocturnal prey item) or, more correctly, for higher net energy gain which is related to prey biomass (Optimal Foraging Theory; see Pyke 1984).

Unfortunately it is not feasible to make direct inferences on prey biomass and habitat for this study as one of the primary prey species for the Burrowing Owl, the sagebrush vole (*Lagurus curtatus*), proved to be un-trappable (see Chapter 4). The natural history of the sagebrush vole is poorly understood; they are known to be an upland prairie species and, to some extent, associated with sagebrush (*Artemisia* spp.) communities; opinions differ on vegetation cover requirements, ranging from sparse to dense

(Fagerstone and Ramey 1996; see also Chapter 4 and references therein). Sagebrush voles potentially occupy any upland habitat type, are probably excluded from depressions by the meadow vole (*Microtus pennsylvanicus*), and may or may not occur in edge habitats. Given that the primary prey species for Burrowing Owls in this study, the deer mouse (*Peromyscus maniculatus*), is found in equivalent abundance in all habitats (see Chapter 4, Table 4.3), and meadow voles occur primarily in depressional areas (Birney *et al* 1976), the selection for the depressional – edge complex may afford the owl the best opportunity to encounter many potential prey species. Understanding potential owl-prey relationships would be greatly improved by increased knowledge of sagebrush vole ecology. Additionally, the classification of upland native prairie as a single habitat type, due to the limitations of aerial photo interpretation, may have underestimated the relative importance of more detailed upland community types (see Smoliak *et al.* 1990: 14-18) to foraging owls, and limited differentiation of sagebrush vole habitat.

The relatively lower use of roads by adult males, especially at the foraging level, has positive implications. Juvenile owls are known to favour roads, resulting in high mortality from vehicular collisions (King 1996, Clayton 1997; Todd 2001), a fate seemingly less likely for adult male owls. Indeed no adult owls were found killed on roads for the duration of this study while collision with vehicles is a factor in juvenile mortality rates for the same study area (Darcey Shyry, unpublished data). Males in Saskatchewan were found to select roadside ditches for foraging, however, this habitat bears little resemblance to roadsides in the EID where they have similar characteristics as the adjoining native prairie. However, the characteristics of habitats selected in this study, i.e. higher, dense vegetative cover, are qualitatively consistent to Haug's (1985) results,

where owls selected ungrazed and uncultivated areas with permanent vegetation cover over grazed pastures and cropland. Nevertheless, methodological differences between this and Haug's (1985) study could lead to differences in estimates of habitat selection. Haug waited for radio-tagged owls to come to rest before estimating location, thereby biasing results away from habitats used during hover-hunting bouts. Furthermore, Haug did not take telemetry readings simultaneously, nor did she incorporate telemetry error in the estimation of habitat use, which could lead to increased misclassification of habitats.

The owls in this study area were frequently observed hovering at dusk and occasionally during the day. In addition, movement patterns during telemetry sessions suggested continued reliance on this strategy throughout the night, although no attempt was made to quantify different hunting strategies. Martin (1973) considered hover hunting a rarely used method, especially during times of increased food requirements by owls. The typical behaviour observed during hover hunting bouts was for the owl to fly up from the ground or perch to a height of 20-30m and proceed to hover over one spot for a 5 – 15 second period and then move to a new location a short distance away. On some occasions the owl dropped quickly to a distance half way to the ground and continued hovering for a few seconds before moving off to new area at the original height. On one occasion this drop was followed by a slower, controlled descent to the ground where the owl successfully caught a small mammal. During the final approach to the mouse, the wings were held outstretched and extended high over the back (RAS personal observation).

It is unknown to what extent the owls can sustain this mode of foraging, but they presumably would need to rest after a period of unsuccessful hovering, either on the

ground or more likely on a perch, should one be available. The high ranking found for fenced features within foraging buffers may reflect this behaviour and resting on a perch may afford the owl the opportunity to continue hunting while resting. The use of hovering does, however, have concomitant increases in energy expenditure and must therefore be a more beneficial method then perch hunting. Research on another hover hunting raptor, the American Kestrel (*Falco sparverius*), found that hovering increased with increased energetic demands and gross energy intake was significantly greater during hover-hunting versus perch-hunting sessions (Rudolph 1982). Toland (1987) found increased use of hover hunting by American Kestrels with increased vegetative cover, but noted perch hunting to be most efficient in terms of energetic returns. He noted that capture rates were greater than in previous studies, which was attributed to increased abundance of a primary prey species.

This study was designed to determine Burrowing Owl habitat selection and has shown that male Burrowing Owls are selectively choosing habitats in relation to their type and structure. While not all extrinsic factors that may be influencing this selectivity have been explored (*e.g.* influence of brood size and travel distances on choice of habitats), depressions and associated edges are important foraging habitat types that managers should incorporate with nesting habitat when developing Burrowing Owl conservation and management strategies.

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CHAPTER 4.

WESTERN BURROWING OWL (*ATHENE CUNICULARIA HYPUGAEA*) DIET AND PREY HABITAT ASSOCIATIONS IN SOUTHERN ALBERTA.

4.0 INTRODUCTION

The primary focus of food habits investigations is to determine the breadth of prey species utilized and which, if any, are being selected preferentially (Korschgen 1980). Biologists and managers use this information to relate a species to its biotic and abiotic environment (Morrison *et al.* 1990), providing improved focus for targeted management and conservation actions.

Burrowing Owl food habits have been documented in many portions of their range (e.g. Gleason 1978, Haug 1985, Plumpton and Lutz 1993a). The focus of these studies has varied from basic descriptions of the diet (Wiley 1998) to the relationships of diet to foraging habits (Gleason 1978) and comparative studies on prey species use versus availability (Gleason 1978, Schmutz *et al.* 1991, Plumpton and Lutz 1993a). Several studies have reported reduced vertebrate and increased invertebrate consumption as the breeding season progressed (Green and Anthony 1989, Haug 1985). In summary, Burrowing Owls take a wide variety of prey species, including mammals, insects, spiders, birds, amphibians, reptiles, and molluscs, with some reports of scavenging (Gervais *et al.* 1997).

Burrowing Owls are considered opportunistic predators, with numerous activity peaks within a 24 h cycle (Martin 1973, Haug 1985). Peaks of activity are related to a temporally and spatially segregated foraging strategy associated with the availability of their primary prey species. Diurnal foraging is predominately for invertebrates (e.g., Orthoptera, Coleoptera), with the owls applying several modes of capture (e.g., hawking,

pouncing, hovering; see Haug 1985 and Martin 1973), and is generally in close proximity to the nest burrow (Martin 1973). Nocturnal foraging is primarily for small mammal species (e.g. Cricetidae, Soricidae), captured either from perches or by hover hunting (personal observation). At night, owls' travel furthest from the nest site in search of appropriate prey habitat (Haug and Oliphant 1990). As outlined in the recovery plan for Burrowing Owls in Canada (Hjertaas *et al* 1995), conservation and management for Burrowing Owls must consider all facets of Burrowing Owl habitat requirements.

The specific goals of this study were to:

1) quantify and analyse the breeding season diet of Burrowing Owls found on native grasslands of southern Alberta and,

2) determine the seasonal changes in prey species composition for Burrowing Owls and,

3) determine habitat associations of the major Burrowing Owl prey groups.

This information can then be used to formulate conservation and management strategies aimed at maintaining adequate prey populations for Burrowing Owls on the native grasslands of western Canada.

4.1 Methods

4.1.1 Study Area

The study site is found in the southeast corner of the Eastern Irrigation District (EID), which is within Newell County and centred by the town of Brooks (50° 33-N 111° 51-W) (Figure 2.1). This area is characterized by hot, dry summers with an average summer (May to August) temperature of 15.8°C and precipitation of 178 mm making it one of the most arid regions of Alberta. Mean winter (November to February)

temperature is –8.6 ° C and typified by shallow snow depths and frequent Chinook winds that tend to remove previous snow accumulation (Strong and Leggat 1992).

The study site encompasses an area of approximately six townships (475 km^2), portions of which were previously selected as survey sites to monitor Burrowing Owl population trends in the province (total area = 61 km^2; Figure 2.2) (Schmutz and Wood 1991, Shyry 1999) and were considered unavailable for this study. Nests that were located within these areas were monitored for productivity by observation from a vehicle (see Chapter 2 for further details on nest searching techniques).

The study site is predominantly native rangelands of needle-and-thread grass (*Stipa comata*), blue grama grass (*Bouteloua gracilis*) and western wheatgrass (*Agropyron smithii*), with some seeded pastures of Russian wildrye (*Elymus* sp.) and crested wheatgrass (*A. cristatum)* and dryland crops. Reservoirs and wetlands with permanent open water are found in the northern and southwestern portions of the study site. Oil and shallow gas developments and related facilities and access roads are common and represent the major fragmenting influence on the landscape.

4.1.2 Pellet Collection

Nests were visited on a four to five day schedule to determine successful pairing, stage of reproductive development, and to collect pellets from the nest and associated roost sites for diet analysis. Nests were observed for 5-10 minutes prior to pellet collection. Visit duration to the nest was from 5 to 15 min, depending on the proximity of roost burrows to the nest. During each visit, all activities were recorded including timing and purpose, number and sex of owls seen, and prey remains and pellets at the nest and roost burrow entrances. Pellets from nests and roosts were placed in separate paper bags

and stored for diet analysis. Feathers from bird prey remains were collected for species identification but were not used for quantification of passerines in the diet.

The relatively high frequency of nest visits was necessary because Burrowing Owl pellets can contain a high proportion of invertebrate material that decays rapidly in the environment (Marti 1974). An additional motive was to accurately determine the initiation of each stage of the nests development in order to separate the pellets into pre- and post hatching periods. This was accomplished by using female behavioural clues, as it was impossible to directly monitor reproductive stage due to the owl's underground nest. The following assumptions of female behaviour with respect to nest development were made:

1) if, on approaching the nest, the female flew away rather than retreating down the nest burrow, then egg laying had not commenced;
2) once the female started retreating down the burrow, egg laying had commenced;
3) when the female was not observed for several visits, incubation had been initiated between the last visit the female was observed and the subsequent visit; and
4) once the female reappeared after a prolonged absence, hatching had begun.

These assumptions are based on personal field observations and those of Wellicome (pers. comm.) in Saskatchewan using artificial nest boxes, as well as the relevant literature (Martin 1973; Gleason 1978; Henny and Blus 1981; Gleason and Johnson 1985; Haug 1985; Haug *et al* 1993). Additionally, Wellicome (2000) found the

onset of incubation to vary with respect to clutch size, hence the assumed delay between the commencement of egg laying and incubation noted above.

4.1.3 Diet Analysis

Burrowing Owl diet was determined through the analysis of a sub-sample of all pellets collected. A maximum of four pellets from each site and collection date was randomly chosen, two each from the nest and roost. Pellets were teased apart by hand to separate vertebrate and invertebrate materials (Marti 1987). Small mammals were enumerated based on the number of unique cranial fragments present in the pellet and identified by dentition to species (Marti 1987), except for the shrew family (Soricidae) which were all assumed to belong to genus *Sorex*. Bones were compared to specimens obtained from the Zoology Museum at the University of Alberta as well as to the mammal guides of Pattie and Hoffman (1990) and Smith (1993). Avifauna were enumerated based on the presence of bones, beaks and feathers in the pellets and were identified to order only (Passeriformes). Insects were identified to the family level and enumerated through the examination of head capsules, mandibles, elytra and ovipositors. Coleopterans were identified with the assistance of an entomologist and by examination of specimens at the University of Alberta Entomology Museum.

The total biomass contributed by each prey species to each Burrowing Owl pair's diet was calculated by multiplying the prey items estimated mean weight (Table 4.1) by the total number counted, for each of the pre- and post hatch periods. This number was then divided by the total biomass for all prey species to give an estimated proportional contribution of each prey species to the diet of the Burrowing Owl pair for that period (Marti 1987). Unidentified Cricetids were assigned the average weight of all specimens

captured in the study area. Pellet collections were separated into pre- and post-hatch periods to evaluate changes in the diet over time. Hatching dates were determined for each nesting attempt using the female behavioural clues described above or, preferentially, by backdating from captured chicks aged using growth curves for flattened wing cord, ninth primary, and central tail feather (Wellicome unpublished data).

Table 4.1. Biomass of Burrowing Owl prey items and sources of estimates.

Prey Items	Estimated Weight (g)	Source
Unidentified Cricetidae	22.0	This study
Peromyscus maniculatus	19.5	This study
Lagurus curtatus	30.0	Steenhoff 1983
Microtus pennsylvanicus	25.0	This study
Onychomys leucogaster	26.0	This study
Sorex spp.	6.0	Steenhoff 1983
Passeriformes	23.0	Steenhoff 1983
Unidentified Coleoptera	0.4	Marti 1974; Sage 1982
Silphidae	0.7	Marti 1974; Sage 1982
Carabidae	0.4	Marti 1974; Sage 1982
Tenebrionidae	0.6	Marti 1974; Sage 1982
Scarabeidae	0.4	Marti 1974; Sage 1982
Other Coleoptera	0.4	Marti 1974; Sage 1982
Acrididae	0.6	Schell and Schell 1994
Rhaphidophoridae	0.5	Schell and Schell 1994
Hemiptera	0.1	Estimate

4.1.4 Sampling of Prey Communities

Six locations for sampling prey were selected throughout the study area in 1998 and were re-used in 1999 (Figure 2.2). These sites were chosen to be representative of potential Burrowing Owl foraging sites and encompassed the main visually definable vegetation gradients within the study area. They were assumed to be independent of each other based on the premise that they were spaced further apart than typical seasonal movement distances of the prey species being sampled.

Each site was located within and around small depressions, with two sites containing dugouts. Within each site, six transects were spaced at 100m intervals, with the first transect located at the centre of the depression, parallel to the edge. The second transect was located along the edge, with each subsequent transect moving away from the edge at 100m intervals into the uplands (Figure 4.1). In both years, cattle grazed four of the sites during the period of prey sampling while the remaining two sites were located in pastures grazed after the sampling was complete.

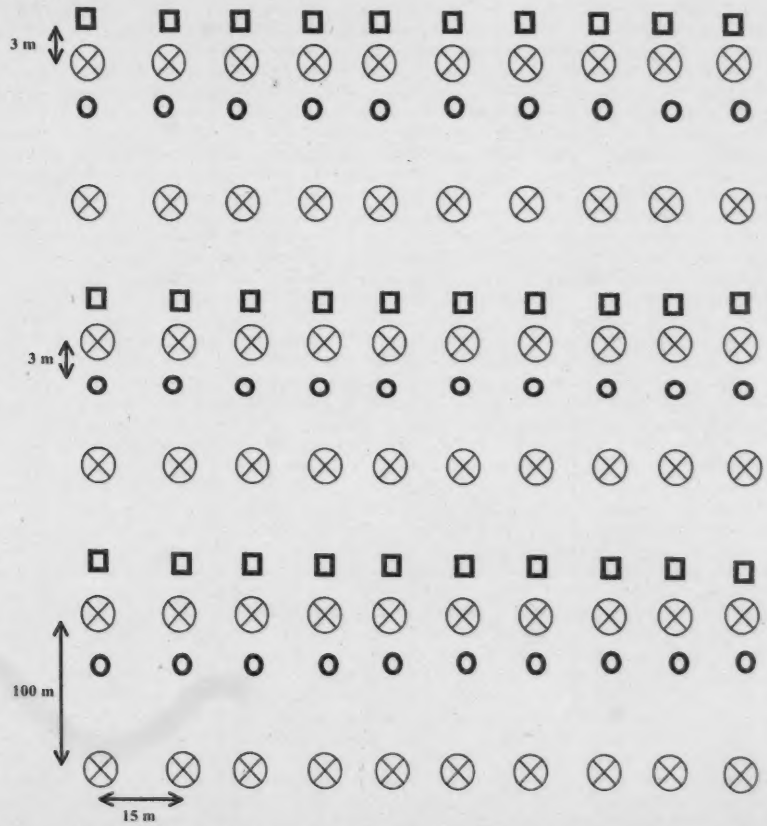

Figure 4.1 Details of prey sampling grids on the Burrowing Owl study area within the Eastern Irrigation District southeast of Brooks, Alberta. Each grid consists of 6 transects of 10 small mammal live traps ⊗ with transects and traps spaced at 100 m and 15 m intervals, respectively. Every second transect had 10 grasshopper flushing frames □ and 10 beetle pitfall traps ○ placed ~3 m to the north or south of the small mammal traps. See text for complete details of prey sampling grid placement.

Along each transect, 10 small mammal live traps were placed at 15 m intervals for a total of 60 traps per site. Trapping sessions were conducted concurrently during the new moon phase of July and August 1998 and June, July, and August 1999. Traps were prebaited with peanut butter and rolled oats and locked open for one week prior to trapping. They were opened in the evenings (1900 – 2100 hrs) and checked the next morning (0800 – 1100 hrs) for three consecutive nights (Davis 1990). Traps were closed during the day throughout the active trapping period and left locked open and in place between trapping periods. All small mammals captured were identified to species and individually marked with an ear tag. The sex, weight, reproductive status, and trap and transect number were recorded and the animal was released at the point of capture.

A Sherman style small mammal live trap was used in 1998, but the large entrance (8.0 X 8.0 cm) to this trap permitted Richardson's ground squirrels (*Spermophilus richardsonii*)– an infrequent prey item for Burrowing Owls (Schmutz *et al* 1991; Plumpton and Lutz 1993a) - to be captured. Of particular concern was the ability of *S. richardsonii* to access closed traps during the day, invariably leading to death. A Longworth style live trap with a smaller entrance (5.0 X 4.0 cm) and better closing mechanism was used in 1999, which prevented access to *S. richardsonii* when the trap was closed; however, it did not reduce captures of *S. richardsonii* when the trap was set.

Grasshoppers were sampled using a 0.25 m^2 wire flushing frame (Onsager and Henry 1977; Legg *et al.*1996). Frames were placed opposite small mammal traps on three transects within each prey sampling site (Figure 4.1). Grasshoppers were quantified by tallying individuals that either flushed when approached or flushed when a hand was brushed over the vegetation within the frame. Grasshoppers were sampled for two

consecutive days in late June and July of 1998 and mid June, July, and August of 1999 during early to mid afternoon (1300 – 1700 hrs), on clear, warm days, when grasshopper activity is at its peak (Schell and Schell 1994).

Relative abundance of Coleopterans was assessed using dry, uncovered round pitfall traps (455 ml plastic cups), placed flushed with the ground surface (Spence and Niemela 1994). Pitfalls were placed on the same transects as grasshopper flushing frames on the opposite side of the small mammal trap (Figure 4.1). Pitfalls were sampled at 24 hr intervals for two days, with all beetles from the first collection removed off site. Beetle sampling was concurrent with grasshopper sampling, except none was conducted in August 1999. Specimens of beetles were collected and frozen for future identification.

4.1.5 Measurement of Habitat Variables

Habitat variables were recorded along each prey sampling transect. Percent cover using Daubenmire cover classes was recorded within a 20 X 50-cm quadrat (Kent and Coker 1996) for each plant species, total forbs, total grasses, total vegetation, bare soil, litter, and moss/lichen. Litter depth was also recorded at the corners of each quadrat. Forty-one quadrats per transect were sampled by tossing the quadrat ~ 3-6 m at 0°, 90°, 180°, and 270° from each small mammal trap and towards the trap from one of these points, except that only one quadrat was sampled between traps. Silver sage (*Artemisia cana*) density was visually estimated at the first, middle, and last trap of each transect as a categorical variable based on Alberta Rangeland Inventory guidelines (Wroe *et al* 1988). An estimate of current grazing pressure on each transect was made by visually estimating the percentage of vegetation within each quadrat that showed signs of having been grazed (i.e. defoliated). Vegetation structure was recorded at each trap and at 5 m from the trap

in each of the cardinal directions using a Robel pole (Bureau of Land Management 1996). The standard measurement of the lowest point on the pole where the vegetation completely obscures the pole at a 4 m distance was recorded (Bureau of Land Management 1996).

4.1.6 Data Analysis

For each trapping session, small mammal trapping results were standardized to the number of individuals of each species per 100 trap nights for each transect. The number of trap nights was corrected for sprung traps following the procedure of Nelson and Clark (1973), which compensates for these traps not being available for the full night of trapping. Grasshopper data were converted to # m^{-2} and averaged for each two day session. Beetles were totalled for the two day sampling period because individuals from the first capture were removed. Each of these values was then averaged over all trapping sessions to obtain an index of relative abundance for each prey category, per transect, per season. Habitat variables were averaged for each transect. A secondary variable, range condition –a measurement of the seral stage of the plant community that can be related in part to historical grazing pressure (Holochek *et al.* 1998) - was derived from the plant species coverage data following the procedure of Wroe *et al.* (1988) with the range score kept as a continuous variable for statistical analysis.

Stepwise multiple regression analysis was used to investigate the relationship of independent habitat variables to the relative abundance of each prey category. Where necessary, variables were transformed (log or square root) to meet the assumptions of the regression analysis (Zar 1996). Prior to analysis, variables were tested for collinearity by constructing a correlation matrix, with a Pearson coefficient of ≥ 0.600 used as a

cutoff point. The decision as to which correlated variable to exclude was dependent on the ease of measurement of each variable in the field, its collinearity with other variables and their level of correlation with the dependant variables. Variables were entered into the model at $p \leq 0.10$ and removed at $p > 0.10$. Residuals were assessed for normality by constructing a normal probability plot (Wilkinson 1997).

Between year differences in abundance of beetles and grasshoppers were tested using a Mann-Whitney, nonparametric test (Zar 1996) prior to pooling across years. Small mammal values were not pooled due to the confounding influence of changing trap types in 1999, and were therefore analyzed separately. Within and between year differences in food habits were also compared using Mann-Whitney tests.

Changes in diet from pre- to post-hatching periods within and between years were assessed using Mann-Whitney nonparametric tests for each prey group and species. Statistical significance was assumed at $p \leq 0.05$, with all procedures performed on SYSTAT 7.0 software (SPSS Inc. 1997).

4.2 Results

4.2.1 Pellet Analysis

A total of 925 pellets were analyzed from 17 nest sites from 1998 and 1999 (Table 4.2). Vertebrates were the dominant prey category by weight taken in both years. Deer mice (*Peromyscus maniculatus*) were the main prey species for all periods except pre-hatch 1998 where sagebrush voles (*Lagurus curtatus*) dominated. Sagebrush voles were the second ranked vertebrate species followed by unidentified passerines, meadow voles (*Microtus pennsylvanicus*), shrews (*Sorex* sp.), and northern grasshopper mice (*Onychomys leucogaster*). Coleopterans of several families were the predominant

Table 4.2. Percent biomass of prey items from pellets of Burrowing Owls from the Eastern Irrigation District study site in southern Alberta, 1998-1999. Number in brackets represents the number of nests analysed for that period. "T" indicates trace amounts (< 0.1 %). Within a row, means with different letters differ significantly ($p \leq 0.05$).

	1998		1999	
Prey Items	Pre-Hatch (8)	Post-Hatch (7)	Pre-Hatch (8)	Post-Hatch (9)
Vertebrates	**88.0**	**81.4**	**87.7^{A}**	**79.7^{B}**
Cricetidae	74.3	73.5^{A}	71.4	64.5^{B}
Unidentified	24.6	26.6^{A}	26.1^{A}	18.5^{B}
Peromyscus maniculatus	18.3^{A}	22.1	29.5^{B}	21.3
Lagurus curtatus	22.0	17.7	10.2	15.1
Microtus pennsylvanicus	8.6	6.8	4.4	8.9
Onychomys leucogaster	0.8	0.3	1.2	0.7
Soricidae	1.3	2.6^{A}	2.9	4.9^{B}
Sorex spp.	1.3	2.6^{A}	2.9	4.9^{B}
Passeriformes	12.5	5.4	13.5	10.4
Invertebrates	**12.0**	**18.6**	**12.3^{A}**	**20.4^{B}**
Coleoptera	8.9	15.2	6.8^{A}	15.0^{B}
Unidentified	4.4	8.7	2.4^{A}	7.2^{B}
Silphidae	2.3	3.1^{A}	2.5	1.9^{B}
Carabidae	1.7	2.1^{A}	1.4^{A}	3.5^{B}
Tenebrionidae	0.4^{a}	1.0^{b}	0.4^{A}	1.7^{B}
Scarabeidae	T^{A}	0.3^{B}	0.1	0.5
Other Coleoptera	T	T	0.1	0.2
Orthoptera	3.1	3.3	5.5	5.4
Acrididae	2.7	1.3^{A}	5.4	5.0^{B}
Rhaphidophoridae	0.4	2.0	0.1	0.4
Hemiptera	T	T	T	T
Pellets analysed	164	237	226	298
$\bar{x}$ pellets analysed nest^{-1} ± SE	21 ± 2.2	34 ± 3.3	29 ± 1.1	33 ± 3.1

invertebrate order, followed by Orthopterans, with Hemipterans contributing a negligible proportion. At the family level, grasshoppers (Acrididae: probable *Xanthippus, Arphia* and *Melanoplus* species) were the prevalent invertebrates for all periods except for the post-hatch 1998 period, where beetles in the Silphidae and Carabidae families were more prominent. The carrion beetle family (Silphidae: majority are species of *Nicrophorus*) dominated the Coleopterans followed by ground beetles (Carabidae: including *Calosoma, Passimachus,* and *Agonum* species), darkling beetles (Tenebrionidae: mainly *Eleodes* and *Embaphion* species) and scarab beetles (Scarabeidae: including genus *Onthophagus* and *Trox*). Other families of beetles included blister beetles (Meloidae), long-horned beetles (Cerambycidae), snout beetles (Curculionidae), pill beetles (Byrrhidae) and predacious diving beetles (Dytiscidae). The final conspicuous invertebrate prey of Burrowing Owls was the camel cricket (Rhaphidophoridae), which reached peak utilization in the 1998 post-hatch period. Infrequent prey items found in pellets included an unknown bat, Vespertilionidae: *Myotis* sp.; Richardson's ground squirrel, Sciuridae: *Spermophilus richardsonii*; unknown spider (Salticidae); and a juvenile Burrowing Owl, Strigidae: *Athene cunicularia*. Inanimate material included eggshells and frequent occurrence of vegetation.

Within year changes in Burrowing Owl consumption of prey species were consistent in 1998 and 1999: invertebrates increased and vertebrates decreased in biomass as the season progressed for both years; although this change was only significant in 1999. The decreased consumption of vertebrates in 1998 was due to a sharp, but insignificant, decrease in passerine biomass; indeed, small mammal biomass increased slightly during the season in 1998, as opposed to decreasing in 1999. In 1998,

only Tenebrionid and Scarabid utilization increased significantly from the pre- to post-hatching periods. In 1999, owl estimated consumption of Coleopterans as a group, and Carabids and Tenebrionids individually, significantly increased during the course of the breeding season (Table 4.2).

Between year differences at the larger level of prey groupings were fairly similar, except for Cricetids, which declined in use for the 1999 versus 1998 post-hatch period. Changes in small mammal consumption are noted by the significantly higher use of *P. maniculatus* in the pre-hatch period and *Sorex* in the post-hatch period of 1999 versus 1998. Carabids and Acridids were utilized significantly greater in the 1998 versus 1999 post-hatching stages while Silphids were the only insect family to be utilized significantly less (Table 4.2).

4.2.2 Prey Remains

Horned Larks (Alaudidae: *Eremophila alpestris*) accounted for the largest proportion (57 %) of identified passerine prey remains, followed by Chestnut-collared Longspur (Emberizidae: *Calcarius ornatus*) at 28 %. The remaining passerines included sparrows (12 %) (mainly Baird's Sparrow (Emberizidae: *Ammodramus bairdii*) and Savannah Sparrow (Emberizidae: *Passerculus sandwichensis*)) and Western Meadowlark (Icteridae: *Sturnella neglecta*). Additional avifauna remains included a Franklin's Gull (Laridae: *Larus pipixcan*), an Eared Grebe (Podicipedidae: *Podiceps nigricollis*), and the legs of an unidentified shorebird (Scolopacidae). Other prey remains not identified in pellets include dragonflies (Odonata), garter snakes (Colubridae: *Thamnophis* sp.), Canada toad (Bufonidae: *Bufo hemiophrys*), Boreal chorus frogs (Hylidae: *Pseudacris maculata*) and tiger salamanders (Ambystomatidae: *Ambystoma tigrinum*).

4.2.3 Prey Abundance

Four species of small mammals were caught during the trapping sessions: deer mice and meadow voles were caught in both years while grasshopper mice and shrews were captured only in 1999. Sagebrush voles were not captured at all during the live trapping sessions, despite their prominence in the owl's diet – every owl pair had sagebrush voles as a key component in their diet. Deer mouse was the only species caught in sufficient numbers for statistical analysis of habitat associations for both years.

Deer mice were present on all sampled habitat types in both years. In 1998, meadow voles were trapped in low numbers on one depression transect only, while in 1999 they were caught in low numbers on four of six depression transects as well as on one edge and one upland transect. Shrews were not captured in 1998, but were present in all habitat types in 1999, while grasshopper mice were present on upland and edge transects, with no individuals captured in depressions. Between year differences may be attributable to the change in trap types in 1999. Beetle and grasshopper abundances did not differ significantly ($p > 0.05$) between years (Table 4.3).

4.2.4 Prey Habitat Associations

Habitat variables were poor predictors of deer mouse abundance in 1998 and 1999. However, the grazing intensity index was a highly significant factor in 1999, with deer mice showing a negative response to increasing cattle usage of an area. Invertebrates also responded to the grazing index, but in the opposite direction. Grasshoppers and beetles showed significant positive relationships with increasing grazing index values. Grasshoppers also responded positively to increasing litter cover and beetles responded positively to litter depth (Table 4.4).

Table 4.3. Relative abundance of Burrowing Owl prey species from the Eastern Irrigation District study site in southern Alberta, 1998-1999. Numbers in brackets indicate the number of transects for small mammal trapping and invertebrate sampling, respectively.

		Small Mammals ($\bar{x}$ # per 100 trap nights ± SE)				Invertebrates	
		Peromyscus maniculatus	*Microtus pennsylvanicus*	*Onychomys leucogaster*	*Sorex* spp.	Coleoptera ($\bar{x}$ # per transect ± SE)	Acrididae ($\bar{x}$ # per m^2 ± SE)
Uplands (18, 12)	1998	5.4 ± 0.69	0.0	0.0	0.0	24.9 ± 2.67	3.0 ± 0.35
	1999	11.5 ± 1.36	0.1 ± 0.06	0.9 ± 0.31	0.2 ± 0.18	27.8 ± 3.28	2.2 ± 0.31
Edge (6, 6)	1998	4.3 ± 1.25	0.0	0.0	0.0	29.3 ± 3.80	2.8 ± 0.69
	1999	7.5 ± 1.67	0.2 ± 0.21	0.7 ± 0.51	0.2 ± 0.21	42.8 ± 8.29	3.3 ± 0.40
Depression (6, 0)	1998	2.8 ± 1.65	1.1 ± 1.11	0.0	0.0	NA	NA
	1999	8.3 ± 2.27	0.8 ± 0.34	0.0	0.2 ± 0.20	NA	NA
Landscape (36, 18)	1998	4.8 ± 0.58	0.2 ± 0.19	0.0	0.0	26.4 ± 2.18	2.9 ± 0.32
	1999	10.3 ± 1.05	0.2 ± 0.08	0.7 ± 0.22	0.2 ± 0.08	32.8 ± 3.78	2.6 ± 0.27

Table 4.4. Response of Burrowing Owl prey groups to habitat variables from regression analysis in native Mixed Grass prairie in southern Alberta, 1998 - 1999.

	Sign of regression coefficient			
Habitat variable	Beetles	Grasshoppers	Deer mice 99	Deer mice 98
Grazing index	+***	+***	–***	
Soil cover	+*			
Litter cover		+**		–*
Grass cover			–*	
Litter depth	+**			
	$F_{(3,14)} = 7.861$	$F_{(2,15)} = 11.328$	$F_{(2,33)} = 12.047$	$F_{(1,34)} = 3.743$
	adj. $R^2 = 0.55$	adj. $R^2 = 0.55$	adj. $R^2 = 0.39$	adj. $R^2 = 0.07$
	$p = 0.003$	$p = 0.001$	$p < 0.001$	$p = 0.061$

* $p \leq 0.1$, ** $p \leq 0.05$; *** $p \leq 0.01$

4.3 Discussion

4.3.1 Food Habits

Burrowing Owls in this area were found to rely on small mammals as their main food source throughout the breeding season, with only a moderate decline in percent biomass from the pre- to post- hatching period in 1999. Passerine use declined, and invertebrate use increased, as the breeding season progressed. The yearly vertebrate: invertebrate ratio from this study follow similar trends as that reported from other authors (Marti 1974, Gleason and Johnson 1985, Green and Anthony 1989) with some expected shifts in family or species due to the geographic location of the study. Differences were noted for studies conducted within Canada, where species assemblages are consistent with the EID site. For example, Haug (1985) found substantially higher utilization of grasshoppers in central Saskatchewan and Schmutz *et al.* (1991) recorded a higher vole to mouse ratio at Hanna, Alberta, located approximately 100 km north of the EID (voles: mice - Hanna: 1.45:1.00; EID: 0.74:1.00). Consistent with the EID results, Schmutz *et al.* (1991) noted a seemingly large occurrence of *Nicrophorus* beetles in pellets, and Haug

(1985) identified Horned Larks and Chestnut-collared Longspurs to be dominant passerine prey remains.

When comparing seasonal changes in diet, most authors report data on a percent frequency basis (e.g. Marti 1974, Plumpton and Lutz 1993a), which can mask actual changes in prey consumption because it does not account for possible increases in prey use during the breeding season. For example, apparent prey consumption in this study, measured on a per pellet basis, increased during the breeding season by 3.2 and 5.2 individuals per pellet in 1998 and 1999, respectively, with invertebrates accounting for the majority of the increase (Table 4.5). The mean number of individual small mammals per pellet remained relatively constant in both years (actually increasing slightly in 1998) from the pre- to post-hatching periods. However, the percent frequency of occurrence for small mammals as a group declined from the pre- to post-hatching periods in both years, erroneously suggesting decreased reliance on small mammals as an important food source during the critical post-hatch or brood rearing period. It is unknown what effect this discrepancy may have had on similar studies of Burrowing Owl feeding habits (summarized in Haug *et al.* 1993) where a significant difference in seasonal prey use was indicated based on percent frequency data. Estimating the contribution of each prey category on a percent biomass basis also masks increasing prey consumption, but accurately depicts seasonal changes in prey contribution to the diet (Table 4.2). Dietary analysis for Burrowing Owls should endeavour to include a bioenergetic approach as applied for other species (e.g. passerines, Rotenberry 1980), where questions about energetic equivalency of dominant prey items can be examined (see Golley 1960 and 1961). For instance, do small mammals and insects have similar caloric content

Table 4.5. Percent frequency and number of individuals per pellet for the major prey groups for Burrowing Owls in the Eastern Irrigation District study site in southern Alberta, 1998-1999. Note the discrepancy in perceived trends in the use of small mammals between the two methods occurring due to an increase in prey consumption from the pre- to post-hatching periods.

	1998				1999			
	Pre-hatch		**Post-hatch**		**Pre-hatch**		**Post-hatch**	
	% Frequency	# Pellet^{-1}	% Frequency	# Pellet^{-1}	% Frequency	# Pellet^{-1}	% Frequency	# Pellet^{-1}
Small mammals	12.33	0.85	9.38	0.94	14.46	1.07	7.96	1.03
Insects	85.98	5.91	90.03	9.03	83.45	6.18	91.02	11.74
Passerines	1.69	0.12	0.59	0.06	2.09	0.15	1.01	0.13
Total		6.87		10.03		7.41		12.90

on a per gram basis and does increased reliance on invertebrates in the critical post-hatching stage reflect discrepancies?

4.3.2 Prey Habitat Associations

Deer mice, sagebrush voles, meadow voles, and unidentified Cricetids dominated the diet of Burrowing Owls in this study. Deer mice and meadow voles were captured during live trapping sessions while the sagebrush vole was not captured, despite its prominence in the diet. Little is known about this species of vole in Canada, as it is generally an incidental capture in rodent studies (MacCracken *et al* 1985a, Reynolds *et al* 1999) unless effort is spent specifically targeting the species (Mullican and Keller 1986, 1987). The deer mouse and meadow vole are fairly well-studied species in the grassland environments of the United States (see Fagerstone and Ramey 1996, Kaufman and Kaufman 1997), but there is a lack of complementary studies for prairie Canada (but see Reynolds *et al.* 1999).

Deer mouse is a widespread and adaptable species associated in some regions with early successional or disturbed habitats (Kaufman and Kaufman 1997). Its response to vegetation structure is varied, with some studies reporting positive associations with increased cover (e.g. MacCracken *et al* 1985a) and others negative associations (Grant *et al.* 1982, Fagerstone and Ramey 1996). Reynolds *et al.* (1999) found deer mice were almost four times more abundant in shrub-grassland vegetation zones versus upland grasslands. This study found deer mice to be prolific throughout the vegetation gradients sampled, with a moderate negative response to increased vegetative cover (litter or grass cover) found in both years of sampling. Above average precipitation was recorded for the study area during June 1998, and throughout the summer of 1999 (Table 2.1). This

increased moisture inevitably led to greater vegetation growth. The negative response to grass cover shown by deer mice in 1999 may be indicative of this abnormal event as opposed to this being the normal response.

Meadow voles were generally restricted to low lying areas of tall, dense vegetation, as elsewhere throughout its range (Birney *et al* 1976, Fagerstone and Ramey 1996). Limited information is available for sagebrush voles, with virtually no detailed studies in Mixed Grass Prairie. They are generally thought to be restricted to semi-arid prairies and gently rolling hills with loose, well-drained soils (Carroll and Genoways 1980). Soper (1931) described sagebrush vole habitat in southern Saskatchewan as generally xeric uplands with a variable amount of sagebrush cover and generally sparse grass cover. In Alberta, sagebrush vole habitat was described at one site by Dearden (1969) as slightly elevated knolls with a noticeably greater abundance of sagebrush and grasses, along with runways lacking vegetative cover. Moore (1953) gave a general description of habitats in Alberta as one of highland areas with scanty vegetation with no mention of sagebrush associations. Additional studies of sagebrush vole ecology occur in habitats unrelated to the Mixed Grass Prairie of Alberta (*i.e.* big sagebrush – bunchgrass habitats; O'Farrell 1972, Maser *et al.*1974, Mullican and Keller 1986, 1987).

The grasshopper community in southern Alberta has an equal distribution of species of band-winged (Oedipodinae), slant-faced (Gomphocerinae), and spur-throated (Melanoplinae) grasshoppers, with species of Melanoplinae dominating the group identified as common in this study area (Dan Johnson, Agriculture Canada; pers comm.). Microhabitat selection in grasshoppers is associated with thermoregulation, predator avoidance, oviposition sites, and food resources (Joern 1982, Quinn *et al.* 1991a). Spur-

throated grasshoppers were found to be positively correlated with increased native grass/forb cover on a Colorado mixedgrass prairie site (Craig *et al.* 1999). In Montana, Kemp (1992) found grasshopper assemblages to shift with respect to habitat type: mean number of species remained constant but the actual species present changed across habitat gradients. Grasshopper numbers in the EID study site responded positively to increased litter cover, possibly reflecting an increase in the number of different species associated with this community characteristic.

The beetle assemblage in this study was found to respond positively to increased litter depth and soil cover. While approximately half of the beetles captured during this study were unidentified, Carabids, Tenebrionids, and Scarabids dominated the identified portion, with only a few specimens of other families collected, including *Nicrophorus* sp., which were common in Burrowing Owl pellets. There have been no known studies of Coleopteran habitat associations in Mixed Grass Prairie in Canada. Studies in Mixed Grass Prairie of South Dakota found Tenebrionids, as a community, to increase in number along a gradient of increasing grass cover and changes in soil texture (Quinn *et al.*1990) and Carabids were found to be correlated with increasing soil cover and coarse soil texture (Quinn *et al.* 1991b).

Major Burrowing Owl prey species are responding to changes to the structure of the grassland ecosystem influenced primarily by precipitation and cattle grazing, and the resultant influence on cover, with deer mice showing a significant negative and invertebrates a significant positive association to the current years grazing pressure (*i.e.* grazing index). This variability in prey species association to grazing suggests a requirement for variability in grazing pressure on the landscape in order to maintain

adequate diversity and density of species. Current management of rangelands tend to emphasize systems designed to maximize the distribution and intensity of grazing (*i.e.* stocking density) cattle on the landscape (e.g., rest-rotation grazing systems, Holochek *et al.* 1998), thus potentially reducing the structural and spatial heterogeneity of rangelands (Adler *et al.* 2001, Fuhlendorf and Engle 2001) and associated prey species composition and densities (e.g., grasshoppers, Onsager 2000). Effective management of Burrowing Owl foraging habitat requires strategies that maximize the natural heterogeneity of grasslands systems, as influenced by cattle, and that are adaptable to inevitable variation in climatic conditions. Additional information on the effect of alternative grazing systems on vegetation characteristics in this region would help guide the development of such strategies.

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CHAPTER 5

SYNTHESIS, MANAGEMENT IMPLICATIONS, AND FUTURE RESEARCH DIRECTIONS FOR BURROWING OWL CONSERVATION IN CANADA

5.0 SYNTHESIS

This study was initiated in 1998 with the intention of providing relevant information for land managers and biologists to use in the effective management of Burrowing Owl breeding habitat in Canada. Specifically, I used indirect (radio telemetry) and direct (prey trapping) observational techniques to investigate Burrowing Owl foraging habitat requirements, dietary preferences, and the response of prey densities to habitat characteristics. I demonstrated that foraging male owls are responding to the structure of their environment. I described the breeding season diet of Burrowing Owls, illustrating their predominant use of deer mice, sagebrush voles and Coleopterans. Finally, I was able to describe the habitat relationships of some of the major prey groups and species.

5.1 MANAGEMENT EFFECTS ON BURROWING OWL ECOLOGY

5.1.1 Grazing Effects on Burrowing Owl Prey Communities

The small mammal community in the EID study area exhibits a variable response to grazing intensity (Chapter 4). Deer mice have exhibited mixed responses to cattle grazing with some past studies indicating grazing is beneficial (Fagerstone and Ramey 1996) or essentially benign (Bock *et al.* 1984). However, deer mice were negatively associated with cattle grazing in this study. Cattle presence during trapping sessions may have reduced capture rates directly by changing small mammal activity patterns; this was not tested. As well, aspects of the sample design may have confounded this relationship,

through collinearity with other environmental variables. Meadow vole populations are known to decrease with increasing grazing pressure, due to the removal of vegetative cover (Birney *et al.* 1976, Kaufman and Kaufman 1997). Sagebrush voles are thought to be negatively impacted by grazing due to their association with increased vegetation biomass (Fagerstone and Ramey 1996). However, their association with sagebrush habitat, a community that can expand with increased grazing pressure (Wroe *et al.* 1988), seems to contradict this assumption.

Grazing affects grasshopper communities by changing the structure of the environment, thereby altering food and shelter availability for grasshoppers (Quinn and Walgenbach 1990, Onsager 2000). Melanoplinae and Gomphocerinae are associated with increasing grass/forb cover, and hence decreasing grazing pressure, while species in the Oedipodinae sub-family are associated with moderate to heavily grazed areas (Capinera and Sechrist 1982). In the *Festuca* grasslands of Alberta, grazing was found to increase overall numbers of grasshoppers, with an associated shift in species composition (Holmes *et al.* 1979).

Grazing effects on Coleopteran communities have not been studied, but would presumably be similar to that on Acrididae, in that grazing induced changes in amount of vegetative and soil cover would result in shifts in community assemblages (Quinn *et al.* 1990, 1991). While effective management of livestock may benefit important invertebrate species for Burrowing Owls, stochastic variables such as weather may influence the outcome (Edwards 1960, Kemp and Cigliano 1994, Skinner and Child 2000).

5.1.2 Conclusions on Management Implications

Burrowing Owls require a wide variety of habitat types within native Mixed Grass Prairie landscapes. One of the most important influences on these communities is livestock grazing, and it is with livestock that effective management for Burrowing Owls may be achieved. Livestock are increasingly being recognized as a tool capable of improving wildlife habitats (Severson and Urness 1994, Schmutz 1994), rather than focusing solely on adverse affects (Fleischner 1994, Noss 1994). Through changes in animal distribution, stocking rates, and timing and duration of grazing, manipulation of the environment is possible with the goal of achieving a specific desired outcome (e.g. dense nesting cover for waterfowl; Nazar and Grilz 1995). Conversely, livestock grazing and associated management may have some adverse influences (e.g., McLaughlin and Mineau 1995), which can be detrimental to Burrowing Owl conservation. The persecution of fossorial mammals due to the perceived competition with cattle for forage or due to their destructive habits (Fagerstone and Ramey 1996) is directly counter to needs of the owls for nesting habitat.

Specific to Burrowing Owls, there is a desire to create or maintain a mosaic of structurally diverse habitats; however, by advocating management actions directed solely at Burrowing Owls and their associated prey species, one must consider the potential influence, be it positive or negative, these actions will have on other species in the system (e.g. reptiles, amphibians, non-prey invertebrates and passerines, as well as plant species and communities).

Additional concerns arise over the consistently low ranks found for most industrial influences on the landscape (Chapter 3). While work is being conducted on

determining the direct impacts of industrial activities of Burrowing Owls (Dave Scobie, Avocet Environmental Inc. Brooks, Alberta, personal communication) and in developing mitigation guidelines (Joslin and Youmans 1999, Scobie and Faminow 2000), research is required on the long-term implications of continued loss and fragmentation of native prairie habitats through industrial and other anthropogenic activities. There are positive signs that industrial influences on native prairie ecosystems have been acknowledged with emerging guidelines to mitigate disturbances (e.g. AEUB 2002) and steps taken to minimize disturbance in sensitive areas (e.g. Mutch 1994).

5.2 Future Research

There are still many unanswered questions concerning the cause of Burrowing Owl population declines in Canada. The first recovery strategy for Burrowing Owls in Canada (Hjertaas *et al.* 1995) outlined numerous gaps in the current information Burrowing Owl ecology that is required by managers prior to beginning the task of reversing the Burrowing Owl's decline. Since that report was published, several of the identified research goals have been accomplished, including: reproductive ecology and food limitations (Wellicome 2000); juvenile dispersal in fragmented (Todd 2001) and unfragmented habitats (Clayton 1997); effects of habitat fragmentation (Warnock 1996); identification of the wintering grounds and survey protocols (Holroyd *et al.* 2001); mitigations for industrial disturbances (Scobie and Faminow 2000); and now habitat selection and identification of important prey species (this study).

Suggestions for future research needs for Burrowing Owl conservation will be restricted to questions that have developed over the course of this study. Broader scale and far-reaching directions are adequately addressed by outcomes of recent Burrowing

symposia. In particular, Holroyd *et al.* (2001) have developed action items that encompass all aspects of Burrowing Owl conservation including status assessments (i.e. improving surveying and monitoring protocols), management actions on breeding, migration and wintering grounds, as well as an education component. Additionally, as mentioned previously, interactions between the focus species and other, non-target species are an important consideration for management planning. Incorporating multispecies into the planning process is essential (Knopf and Samson 1997, Derrickson et al. 1998, Herkert and Knopf 1998, Vickery *et al.* 1999, Mace *et al.* 2001).

One of the main research needs stemming from this project is related to cattle grazing and its effect on the prairie environment. This study was unable to establish direct linkages between cattle grazing and Burrowing Owl foraging habitat selection. Also, the relationship between grazing and prey community dynamics was only marginally addressed in this study. Particular attention is required for certain species or groups of prey, specifically sagebrush voles (for which a complete natural history study is essential) and Coleopterans, as both represented significant portions of Burrowing Owl diet. This speaks to the need for long-term grazing experiments in prairie Canada designed to quantify the above relationships in terms of appropriate commercial grazing systems – that is, the experiment should be as relevant to land managers as it is for the target organism(s) (Young and Varland 1998). These experiments should be at spatial scales appropriate for the focal species; that is encompassing Burrowing Owl (or for that matter, all species of interest in a multispecies perspective) perceptions of the environment (Dutilleul 1998) at multiple spatial scales.

Other questions arising from Burrowing Owl dietary analysis relate to the inability of this study to make conclusive statements regarding prey preference, as some primary prey species were not sampled during prey trapping sessions (e.g. sagebrush vole). This shortcoming can only be corrected if an appropriate sampling protocol for this species is developed. One invertebrate group (carrion beetles, Silphidae) was probably underrepresented in sampling plots simply due to the techniques utilized (unbaited pitfall traps), which can be easily corrected in future studies. Further work on Burrowing Owl prey species should also include aspects of the bioenergetic value of selected prey species (see Chapter 4: Discussion and references therein).

An assumption was made in Chapter 3 with respect to the choices made by Burrowing Owls as they arrive on their breeding grounds in the spring. I assumed that the nest burrow is the primary criteria in nest site selection and that nocturnal foraging habitat is a secondary consideration. There is a general lack of understanding of the nest site selection process: for example, do owls search a potential breeding site for the best foraging habitat, and then locate a suitable burrow within this area? If no suitable burrows are located, do they then select a sub-optimal burrow in order to take advantage of the food resources at that site or do they abandon the site? Or, do they secure the best burrow and then make do with whatever foraging habitat is available to them, potentially limiting their reproductive output? Answers to these questions can serve to establish prioritizations in the management of Burrowing Owl habitat; for instance, if owls are abandoning lucrative foraging habitats due to a lack of suitable burrows, then a management strategy that improves the distribution of optimal burrows may be an appropriate tactic. To some degree answering these questions may be possible using

existing data sets from Alberta and Saskatchewan, supplemented with new data. Relating habitat quality (as measured by prey availability, an incomplete dataset) and quantity to home range size and reproductive output would provide managers with the ability to delineate targeted areas for conservation actions, such as protection from cultivation and changes to (or maintenance of) current management practices. Ultimately, compiling existing information collected by Burrowing Owl researchers over the past few decades into one data depository and making this information freely available to biologists will be a required first step for answering these landscape level questions.

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Appendix 1.0 Proportions of habitat variables within Burrowing Owl available buffers, home ranges, core areas, and foraging buffers on the Eastern Irrigation District study site in southern Alberta. The highlighted values within the home range and foraging buffer compositions indicate the individuals dropped from that level of habitat selection analysis due to the zero values in the home range matrix. See text for details.

	Included Habitat Types							Excluded Habitat Types			
	Native uplands	Depressions	Edge	Dugouts	Fenced Features	Gravel Roads	Other manmade features	Vegetated sand dunes	Sand - edge	Tame pastures	Irrigated Crops
Available habitat proportions											
1	80.7	8.7	5.6	0.1	0.8	1.2	2.9	0.0	0.0	0.0	0.0
2	38.8	17.6	5.0	0.3	5.6	2.8	3.1	0.0	0.0	26.9	0.0
3	77.7	10.3	2.6	0.1	3.7	1.3	4.3	0.0	0.0	0.0	0.0
4	78.1	5.1	3.3	0.1	0.7	0.6	2.1	0.0	0.0	0.0	10.1
5	80.6	8.7	5.7	0.1	0.3	1.9	2.7	0.0	0.0	0.0	0.0
6	60.3	15.8	7.4	0.1	1.4	0.9	3.9	0.0	0.0	10.2	0.0
7	64.0	1.7	0.9	0.2	0.2	0.7	2.1	28.1	2.2	0.0	0.0
8	77.3	10.9	6.0	0.2	1.0	0.8	3.9	0.0	0.0	0.0	0.0
9	80.5	9.5	5.4	0.1	1.1	0.6	2.8	0.0	0.0	0.0	0.0
10	82.0	8.0	4.4	0.1	1.5	1.1	2.8	0.0	0.0	0.0	0.0
11	76.4	11.8	5.4	0.1	1.3	1.0	3.9	0.0	0.0	0.0	0.0
95% kernel home range habitat proportions											
1	77.5	11.8	6.2	0.2	1.5	0.5	2.2	0.0	0.0	0.0	0.0
2	34.9	28.0	5.8	0.7	3.7	3.2	2.7	0.0	0.0	21.0	0.0
3	**79.3**	**9.7**	**3.7**	**0.0**	**2.3**	**1.2**	**3.6**	0.0	0.0	0.0	0.0
4	64.5	7.8	3.5	0.6	0.5	0.8	1.4	0.0	0.0	0.0	20.9
5	**69.1**	**18.0**	**6.5**	**0.7**	**0.0**	**1.9**	**3.7**	0.0	0.0	0.0	0.0
6	45.5	12.6	8.5	0.2	2.8	1.1	3.1	0.0	0.0	26.3	0.0
7	**46.6**	**1.2**	**0.6**	**0.5**	**0.0**	**0.4**	**2.2**	45.6	2.9	0.0	0.0
8	75.8	11.1	5.4	0.8	2.9	0.7	3.4	0.0	0.0	0.0	0.0
9	70.2	18.3	5.7	0.4	2.3	0.3	2.9	0.0	0.0	0.0	0.0
10	76.1	11.6	6.1	0.2	1.9	1.8	2.2	0.0	0.0	0.0	0.0
11	69.3	19.2	5.6	0.4	1.0	1.4	3.2	0.0	0.0	0.0	0.0

Appendix 1.0 Continued

	Included Habitat Types							Excluded Habitat Types			
	Native uplands	Depressions	Edge	Dugouts	Fenced Features	Gravel Roads	Other manmade features	Vegetated sand dunes	Sand - edge	Tame pastures	Irrigated Crops
Core area (50% kernel) habitat proportions											
1	76.2	7.1	7.9	0.0	7.7	0.0	1.2	0.0	0.0	0.0	0.0
2	34.6	44.1	4.0	0.0	6.2	6.0	2.5	0.0	0.0	2.6	0.0
3	80.3	10.1	3.6	0.0	3.4	0.7	1.8	0.0	0.0	0.0	0.0
4	66.9	21.2	8.4	0.0	0.0	0.0	0.9	0.0	0.0	0.0	2.6
5	67.4	24.1	2.2	3.1	0.0	0.0	3.2	0.0	0.0	0.0	0.0
6	36.4	15.1	9.4	0.0	5.1	0.2	2.5	0.0	0.0	31.3	0.0
7	55.2	1.8	0.9	0.3	0.0	0.0	1.6	36.9	3.4	0.0	0.0
8	64.8	14.7	5.1	1.1	9.5	0.2	4.6	0.0	0.0	0.0	0.0
9	74.3	13.8	2.8	0.0	3.9	0.0	5.1	0.0	0.0	0.0	0.0
10	69.9	15.2	5.4	1.8	5.1	1.5	1.1	0.0	0.0	0.0	0.0
11	77.8	5.9	5.6	0.0	4.9	3.0	2.7	0.0	0.0	0.0	0.0
Foraging buffer habitat proportions											
1	77.0	8.5	6.3	0.3	5.0	0.9	2.0	0.0	0.0	0.0	0.0
2	30.3	41.5	4.6	1.0	7.4	5.2	1.8	0.0	0.0	8.2	0.0
3	80.5	9.8	3.6	0.0	3.1	0.7	2.4	0.0	0.0	0.0	0.0
4	64.8	10.9	4.9	0.8	0.1	0.4	1.4	0.0	0.0	0.0	16.6
5	70.6	17.3	5.8	1.2	0.0	1.8	3.3	0.0	0.0	0.0	0.0
6	39.4	12.0	9.0	0.0	3.6	0.3	2.1	0.0	0.0	33.6	0.0
7	45.8	1.2	0.5	0.4	0.0	0.3	2.6	46.2	3.0	0.0	0.0
8	72.8	11.1	5.3	1.3	5.3	0.1	4.0	0.0	0.0	0.0	0.0
9	69.7	16.2	5.0	0.1	4.3	0.7	3.9	0.0	0.0	0.0	0.0
10	70.2	16.6	8.2	0.7	1.4	1.6	1.2	0.0	0.0	0.0	0.0
11	71.6	16.2	5.3	0.0	2.0	2.5	2.3	0.0	0.0	0.0	0.0

Appendix 2.0 Output of compositional analysis of habitat proportions for the 95 % kernel home range versus available habitat for eleven male Burrowing Owls. The habitat used as the denominator in the initial log ratio matrices is the "Other" features habitat type; see text for descriptions of habitat variables.

Log ratios of utilized resource

	Depression	Dugout	Edge	Native	Fenced	Roads
1	1.6659	-2.6391	1.0197	3.5432	-0.3747	-1.4043
2	2.3419	-1.2772	0.7614	2.5632	0.3107	0.1798
3	0.9802	-8.1997	0.0298	3.0819	-0.4461	-1.0851
4	1.7035	-0.9305	0.9021	3.8154	-1.0046	-0.5250
5	1.5821	-1.6652	0.5635	2.9273	-8.2160	-0.6665
6	1.4071	-2.7376	1.0060	2.6891	-0.1129	-1.0605
7	-0.6054	-1.4144	-1.3417	3.0630	-7.6870	-1.6236
8	1.1791	-1.4654	0.4512	3.0981	-0.1788	-1.6301
9	1.8348	-1.9879	0.6671	3.1796	-0.2607	-2.4187
10	1.6569	-2.4069	1.0108	3.5349	-0.1400	-0.2265
11	1.7996	-2.1245	0.5587	3.0808	-1.1669	-0.8133

Log ratios of available resource

	Depression	Dugout	Edge	Native	Fenced	Roads
1	1.0975	-3.3638	0.6686	3.3297	-1.2597	-0.9043
2	1.7246	-2.3789	0.4624	2.5166	0.5835	-0.1114
3	0.8753	-3.9797	-0.4908	2.8985	-0.1349	-1.1613
4	0.8845	-3.4059	0.4381	3.6107	-1.0892	-1.3088
5	1.1701	-3.2958	0.7472	3.3962	-2.1972	-0.3514
6	1.3971	-3.4038	0.6352	2.7360	-1.0561	-1.5028
7	-0.2136	-2.2020	-0.8267	3.4262	-2.4472	-1.1479
8	1.0234	-3.0783	0.4199	2.9838	-1.3243	-1.6380
9	1.2177	-3.6960	0.6404	3.3521	-0.9785	-1.5148
10	1.0369	-3.2511	0.4287	3.3628	-0.6055	-0.9128
11	1.0969	-3.4940	0.3145	2.9617	-1.0736	-1.3939

Difference in log ratios

	Depression	Dugout	Edge	Native	Fenced	Roads
1	0.5684	0.7248	0.3511	0.2134	0.8850	-0.5001
2	0.6174	1.1017	0.2990	0.0466	-0.2729	0.2913
3	0.1049	-4.2200	0.5206	0.1834	-0.3113	0.0762
4	0.8190	2.4755	0.4640	0.2047	0.0846	0.7838
5	0.4120	1.6306	-0.1837	-0.4690	-6.0188	-0.3151
6	0.0100	0.6661	0.3708	-0.0469	0.9431	0.4423
7	-0.3919	0.7876	-0.5150	-0.3632	-5.2398	-0.4757
8	0.1557	1.6130	0.0313	0.1143	1.1455	0.0079
9	0.6171	1.7081	0.0268	-0.1725	0.7178	-0.9039
10	0.6201	0.8441	0.5821	0.1721	0.4656	0.6862
11	0.7027	1.3695	0.2442	0.1191	-0.0933	0.5806

R1 - mean-corrected sum of squares and cross products

1	1.3618	2.4874	0.6589	0.3866	3.7611	0.6241
2	2.4874	30.6234	-1.7336	-0.9468	-2.0240	0.2936
3	0.6589	-1.7336	1.0991	0.6630	6.0962	1.1649
4	0.3866	-0.9468	0.6630	0.5640	4.8957	0.7251
5	3.7611	-2.0240	6.0962	4.8957	62.2038	4.4237
6	0.6241	0.2936	1.1649	0.7251	4.4237	3.0602

R2 - raw sum of squares and cross products

1	2.9925	5.8375	1.5025	0.3874	0.7986	0.8834
2	5.8375	37.5060	-0.0004	-0.9451	-8.1104	0.8263
3	1.5025	-0.0004	1.5355	0.6634	4.5635	1.2991
4	0.3874	-0.9451	0.6634	0.5640	4.8942	0.7253
5	0.7986	-8.1104	4.5635	4.8942	67.5862	3.9525
6	0.8834	0.8263	1.2991	0.7253	3.9525	3.1014

R1 = 36.268; R2 = 200.952; Lambda = 0.1805; X^2 6 df = 18.8335 P < 0.01

Matrix of means ± 1 SE

	Depression	Dugout	Edge	Native	Fenced	Roads	Other
Depression		-0.4060	0.1858	0.3848	1.0845	0.3238	0.3850
±		0.4955	0.1019	0.1024	0.7138	0.1699	0.1113
Dugout	0.4060		0.5918	0.7908	1.4905	0.7298	0.7910
±	0.4955		0.5656	0.5484	0.9384	0.5485	0.5276
Edge	-0.1858	-0.5918		0.1990	0.8987	0.1380	0.1992
±	0.1019	0.5656		0.0554	0.6816	0.1290	0.1000
Native	-0.3848	-0.7908	-0.1990		0.6997	-0.0610	0.0002
±	0.1024	0.5484	0.0554		0.6940	0.1406	0.0716
Fenced	-1.0845	-1.4905	-0.8987	-0.6997		-0.7607	-0.6995
±	0.7138	0.9384	0.6816	0.6940		0.7162	0.7520
Roads	-0.3238	-0.7298	-0.1380	0.0610	0.7607		0.0612
±	0.1699	0.5485	0.1290	0.1406	0.7162		0.1668
Other	-0.3850	-0.7910	-0.1992	-0.0002	0.6995	-0.0612	
±	0.1113	0.5276	0.1000	0.0716	0.7520	0.1668	

Matrix of *t* values and probability > |*t*|

	Depression	Dugout	Edge	Native	Fenced	Roads	Other
Depression		-0.8193	1.8229	3.7593	1.5194	1.9063	3.4603
P		0.4317	0.0983	0.0037	0.1596	0.0857	0.0061
Dugout	0.8193		1.0463	1.4420	1.5883	1.3304	1.4992
P	0.4317		0.3200	0.1799	0.1433	0.2129	0.1647
Edge	-1.8229	-1.0463		3.5947	1.3184	1.0698	1.9927
P	0.0983	0.3200		0.0049	0.2168	0.3099	0.0743
Native	-3.7593	-1.4420	-3.5947		1.0082	-0.4341	0.0027
P	0.0037	0.1799	0.0049		0.3371	0.6734	0.9979
Fenced	-1.5194	-1.5883	-1.3184	-1.0082		-1.0622	-0.9302
P	0.1596	0.1433	0.2168	0.3371		0.3131	0.3742
Roads	-1.9063	-1.3304	-1.0698	0.4341	1.0622		0.3671
P	0.0857	0.2129	0.3099	0.6734	0.3131		0.7212
Other	-3.4603	-1.4992	-1.9927	-0.0027	0.9302	-0.3671	
P	0.0061	0.1647	0.0743	0.9979	0.3742	0.7212	

Matrix of resource rankings; 1 = NS; 2 = significant at $\forall \leq 0.10$; 3 = significant at $\forall \leq 0.05$

	Depression	Dugout	Edge	Native	Fenced	Roads	Other	Rank
Depression		-1	2	3	1	2	3	(5)
Dugout	1		1	1	1	1	1	(6)
Edge	-2	-1		3	1	1	2	(4)
Native	-3	-1	-3		1	-1	1	(2)
Fenced	-1	-1	-1	-1		-1	-1	(0)
Roads	-2	-1	-1	1	1		1	(3)
Other	-3	-1	-2	-1	1	-1		(1)

Appendix 2.1 Output of compositional analysis of habitat proportions for the core area (50% kernel) versus available habitat for eleven male Burrowing Owls. The habitat used as the denominator in the initial log ratio matrices is the "Other" features habitat type; see text for descriptions of habitat variables.

Log ratios of utilized resource

	Depression	Dugout	Edge	Native	Fenced	Roads
1	1.7587	-7.1063	1.8645	4.1344	1.8361	-7.1063
2	2.8900	-7.8038	0.5002	2.6481	0.9269	0.8957
3	1.7103	-7.5120	0.6850	3.7822	0.6166	-0.9755
4	3.1367	-6.8236	2.2064	4.2875	-6.8236	-6.8236
5	2.0192	-0.0318	-0.3748	3.0476	-8.0708	-8.0708
6	1.8005	-7.8200	1.3338	2.6834	0.7071	-2.7458
7	0.1136	-1.7316	-0.5302	3.5532	-7.3649	-7.3649
8	1.1685	-1.4220	0.1119	2.6543	0.7361	-3.0315
9	1.0001	-8.5330	-0.5816	2.6833	-0.2542	-8.5330
10	2.6150	0.4553	1.5857	4.1434	1.5307	0.2877
11	0.7690	-7.9120	0.7256	3.3504	0.5768	0.1076

Log ratios of available resource

	Depression	Dugout	Edge	Native	Fenced	Roads
1	1.0975	-3.3638	0.6686	3.3297	-1.2597	-0.9043
2	1.7246	-2.3789	0.4624	2.5166	0.5835	-0.1114
3	0.8753	-3.9797	-0.4908	2.8985	-0.1349	-1.1613
4	0.8845	-3.4059	0.4381	3.6107	-1.0892	-1.3088
5	1.1701	-3.2958	0.7472	3.3962	-2.1972	-0.3514
6	1.3971	-3.4038	0.6352	2.7360	-1.0561	-1.5028
7	-0.2136	-2.2020	-0.8267	3.4262	-2.4472	-1.1479
8	1.0234	-3.0783	0.4199	2.9838	-1.3243	-1.6380
9	1.2177	-3.6960	0.6404	3.3521	-0.9785	-1.5148
10	1.0369	-3.2511	0.4287	3.3628	-0.6055	-0.9128
11	1.0969	-3.4940	0.3145	2.9617	-1.0736	-1.3939

Difference in log ratios

	Depression	Dugout	Edge	Native	Fenced	Roads
1	0.6612	-3.7424	1.1959	0.8047	3.0958	-6.2020
2	1.1654	-5.4249	0.0378	0.1315	0.3434	1.0071
3	0.8350	-3.5323	1.1757	0.8836	0.7514	0.1858
4	2.2522	-3.4176	1.7683	0.6769	-5.7344	-5.5148
5	0.8491	3.2641	-1.1220	-0.3486	-5.8736	-7.7194
6	0.4034	-4.4162	0.6985	-0.0525	1.7632	-1.2430
7	0.3272	0.4705	0.2965	0.1270	-4.9178	-6.2170
8	0.1451	1.6563	-0.3079	-0.3295	2.0604	-1.3935
9	-0.2176	-4.8370	-1.2219	-0.6689	0.7243	-7.0182
10	1.5781	3.7063	1.1571	0.7806	2.1363	1.2005
11	-0.3279	-4.4180	0.4111	0.3887	1.6504	1.5015

R1 - mean-corrected sum of squares and cross products

1	5.8724	4.7206	4.2859	2.2050	-9.9641	0.3510
2	4.7206	118.4458	-5.9201	-1.6378	-32.7666	-16.3278
3	4.2859	-5.9201	9.3510	4.6873	3.9400	11.7256
4	2.2050	-1.6378	4.6873	2.8398	2.6656	7.0492
5	-9.9641	-32.7666	3.9400	2.6656	115.5442	72.2947
6	0.3510	-16.3278	11.7256	7.0492	72.2947	134.8971

R2 - raw sum of squares and cross products

1	11.2221	-9.7090	7.1375	3.8742	-12.7540	-21.5558
2	-9.7090	157.3664	-13.6116	-6.1402	-25.2416	42.7609
3	7.1375	-13.6116	10.8710	5.5770	2.4529	0.0484
4	3.8742	-6.1402	5.5770	3.3607	1.7951	0.2137
5	-12.7540	-25.2416	2.4529	1.7951	116.9991	83.7191
6	-21.5558	42.7609	0.0484	0.2137	83.7191	224.6047

R1 = 10304686.38; R2 = 45015165.43; Lambda = 0.2289; X^2 6 df = 16.2184
P = 0.014

Matrix of means ± 1 SE

	Depression	Dugout	Edge	Native	Fenced	Roads	Other
Depression		2.5784	0.3256	0.4798	1.0611	3.5531	0.6974
±		1.0219	0.2459	0.1978	1.1336	1.1284	0.2311
Dugout	-2.5784		-2.2527	-2.0986	-1.5173	0.9747	-1.8810
±	1.0219		1.1267	1.0641	1.6501	1.6124	1.0377
Edge	-0.3256	2.2527		0.1541	0.7354	3.2275	0.3717
±	0.2459	1.1267		0.1600	1.0314	1.0479	0.2916
Native	-0.4798	2.0986	-0.1541		0.5813	3.0733	0.2176
±	0.1978	1.0641	0.1600		1.0138	1.0602	0.1607
Fenced	-1.0611	1.5173	-0.7354	-0.5813		2.4921	-0.3637
±	1.1336	1.6501	1.0314	1.0138		0.9810	1.0249
Roads	-3.5531	-0.9747	-3.2275	-3.0733	-2.4921		-2.8557
±	1.1284	1.6124	1.0479	1.0602	0.9810		1.1074
Other	-0.6974	1.8810	-0.3717	-0.2176	0.3637	2.8557	
±	0.2311	1.0377	0.2916	0.1607	1.0249	1.1074	

Matrix of *t* values and probability > |*t*|

	Depression	Dugout	Edge	Native	Fenced	Roads	Other
Depression		2.5231	1.3243	2.4260	0.9360	3.1487	3.0182
P		0.0302	0.2149	0.0357	0.3713	0.0104	0.0129
Dugout	-2.5231		-1.9994	-1.9721	-0.9195	0.6045	-1.8127
P	0.0302		0.0735	0.0769	0.3795	0.5590	0.1000
Edge	-1.3243	1.9994		0.9633	0.7130	3.0799	1.2750
P	0.2149	0.0735		0.3581	0.4921	0.0116	0.2312
Native	-2.4260	1.9721	-0.9633		0.5734	2.8989	1.3543
P	0.0357	0.0769	0.3581		0.5791	0.0159	0.2055
Fenced	-0.9360	0.9195	-0.7130	-0.5734		2.5404	-0.3548
P	0.3713	0.3795	0.4921	0.5791		0.0293	0.7301
Roads	-3.1487	-0.6045	-3.0799	-2.8989	-2.5404		-2.5788
P	0.0104	0.5590	0.0116	0.0159	0.0293		0.0275
Other	-3.0182	1.8127	-1.2750	-1.3543	0.3548	2.5788	
P	0.0129	0.1000	0.2312	0.2055	0.7301	0.0275	

Matrix of resource rankings; 1 = NS; 2 = significant at $\forall \leq 0.10$; 3 = significant at $\forall \leq 0.05$

	Depression	Dugout	Edge	Native	Fenced	Roads	Other	Rank
Depression		3	1	3	1	3	3	(6)
Dugout	-3		-2	-2	-1	1	-2	(1)
Edge	-1	2		1	1	3	1	(5)
Native	-3	2	-1		1	3	1	(4)
Fenced	-1	1	-1	-1		3	-1	(2)
Roads	-3	-1	-3	-3	-3		-3	(0)
Other	-3	2	-1	-1	1	3		(3)

Appendix 2.2 Output of compositional analysis of habitat proportions for foraging buffers versus the 95% adaptive kernel home range for eight male Burrowing Owls. The habitat used as the denominator in the initial log ratio matrices is the "Other" features habitat type; see text for descriptions of habitat variables.

Log ratios of utilized resource

	Depression	Dugout	Edge	Native	Fenced	Roads
1	1.4393	-1.9761	1.1406	3.6407	0.9003	-0.8196
2	3.1321	-0.5735	0.9306	2.8188	1.4014	1.0515
3	2.0418	-0.5614	1.2304	3.8205	-2.3168	-1.2423
4	1.7520	-7.6448	1.4590	2.9379	0.5326	-2.0106
5	1.0139	-1.1137	0.2783	2.8970	0.2745	-3.4315
6	1.4107	-3.3373	0.2422	2.8737	0.0944	-1.7568
7	2.6024	-0.6075	1.9008	4.0445	0.1507	0.2816
8	1.9466	-7.7493	0.8224	3.4293	-0.1237	0.0867

Log ratios of available resource

	Depression	Dugout	Edge	Native	Fenced	Roads
1	1.6659	-2.6391	1.0197	3.5432	-0.3747	-1.4043
2	2.3419	-1.2772	0.7614	2.5632	0.3107	0.1798
3	1.7035	-0.9305	0.9021	3.8154	-1.0046	-0.5250
4	1.4071	-2.7376	1.0060	2.6891	-0.1129	-1.0605
5	1.1791	-1.4654	0.4512	3.0981	-0.1788	-1.6301
6	1.8348	-1.9879	0.6671	3.1796	-0.2607	-2.4187
7	1.6569	-2.4069	1.0108	3.5349	-0.1400	-0.2265
8	1.7996	-2.1245	0.5587	3.0808	-1.1669	-0.8133

Difference in log ratios

	Depression	Dugout	Edge	Native	Fenced	Roads
1	-0.2265	0.6630	0.1209	0.0976	1.2750	0.5847
2	0.7902	0.7037	0.1692	0.2556	1.0907	0.8716
3	0.3383	0.3691	0.3283	0.0051	-1.3122	-0.7172
4	0.3449	-4.9072	0.4530	0.2488	0.6456	-0.9501
5	-0.1652	0.3517	-0.1729	-0.2011	0.4534	-1.8014
6	-0.4240	-1.3494	-0.4249	-0.3059	0.3550	0.6618
7	0.9454	1.7995	0.8900	0.5095	0.2906	0.5081
8	0.1470	-5.6248	0.2637	0.3485	1.0432	0.8999

R1 - mean-corrected sum of squares and cross products

1	1.6489	1.9757	1.1065	0.7537	-0.2859	0.6031
2	1.9757	53.9838	0.3544	-0.7184	-3.8651	-0.2182
3	1.1065	0.3544	1.0972	0.6846	-0.2765	0.2603
4	0.7537	-0.7184	0.6846	0.5371	0.4089	0.7651
5	-0.2859	-3.8651	-0.2765	0.4089	4.6137	2.5012
6	0.6031	-0.2182	0.2603	0.7651	2.5012	7.2694

R2 - raw sum of squares and cross products

1	2.0317	0.2270	1.4625	0.9633	0.5544	0.6157
2	0.2270	61.9728	-1.2718	-1.6759	-7.7038	-0.2756
3	1.4625	-1.2718	1.4282	0.8795	0.5049	0.2720
4	0.9633	-1.6759	0.8795	0.6519	0.8690	0.7720
5	0.5544	-7.7038	0.5049	0.8690	6.4583	2.5288
6	0.6157	-0.2756	0.2720	0.7720	2.5288	7.2699

R1 = 5.2333; R2 = 38.1246; Lambda = 0.1373; X^2 6 df = 15.8866; P = 0.016

Matrix of means ± 1 SE

	Depression	Dugout	Edge	Native	Fenced	Roads	Other
Depression		1.2181	0.0153	0.0990	-0.2614	0.2116	0.2187
±		0.9607	0.0976	0.1101	0.3493	0.3711	0.1716
Dugout	-1.2181		-1.2027	-1.1191	-1.4795	-1.0065	-0.9993
±	0.9607		0.9854	0.9996	1.0883	1.0496	0.9818
Edge	-0.0153	1.2027		0.0836	-0.2768	0.1962	0.2034
±	0.0976	0.9854		0.0688	0.3344	0.3743	0.1400
Native	-0.0990	1.1191	-0.0836		-0.3604	0.1126	0.1198
±	0.1101	0.9996	0.0688		0.2782	0.3348	0.0979
Fenced	0.2614	1.4795	0.2768	0.3604		0.4730	0.4802
±	0.3493	1.0883	0.3344	0.2782		0.3505	0.2870
Roads	-0.2116	1.0065	-0.1962	-0.1126	-0.4730		0.0072
±	0.3711	1.0496	0.3743	0.3348	0.3505		0.3603
Other	-0.2187	0.9993	-0.2034	-0.1198	-0.4802	-0.0072	
±	0.1716	0.9818	0.1400	0.0979	0.2870	0.3603	

Matrix of *t* values and probability > |*t*|

	Depression	Dugout	Edge	Native	Fenced	Roads	Other
Depression		1.2679	0.1572	0.8992	-0.7483	0.5701	1.2748
P		0.2454	0.8796	0.3984	0.4786	0.5864	0.2431
Dugout	-1.2679		-1.2206	-1.1195	-1.3594	-0.9589	-1.0178
P	0.2454		0.2618	0.2999	0.2162	0.3695	0.3427
Edge	-0.1572	1.2206		1.2158	-0.8275	0.5243	1.4532
P	0.8796	0.2618		0.2635	0.4353	0.6163	0.1895
Native	-0.8992	1.1195	-1.2158		-1.2956	0.3363	1.2229
P	0.3984	0.2999	0.2635		0.2362	0.7465	0.2609
Fenced	0.7483	1.3594	0.8275	1.2956		1.3494	1.6729
P	0.4786	0.2162	0.4353	0.2362		0.2192	0.1383
Roads	-0.5701	0.9589	-0.5243	-0.3363	-1.3494		0.0199
P	0.5864	0.3695	0.6163	0.7465	0.2192		0.9847
Other	-1.2748	1.0178	-1.4532	-1.2229	-1.6729	-0.0199	
P	0.2431	0.3427	0.1895	0.2609	0.1383	0.9847	

Matrix of resource rankings; 1 = NS; 2 = significant at $\forall \leq 0.10$; 3 = significant at $\forall \leq 0.05$

	Depression	Dugout	Edge	Native	Fenced	Roads	Other	Rank
Depression		1	1	1	-1	1	1	(5)
Dugout	-1		-1	-1	-1	-1	-1	(0)
Edge	-1	1		1	-1	1	1	(4)
Native	-1	1	-1		-1	1	1	(3)
Fenced	1	1	1	1		1	1	(6)
Roads	-1	1	-1	-1	-1		1	(2)
Other	-1	1	-1	-1	-1	-1		(1)